93801

J. C. Branner

THE

QUARTERLY JOURNAL

OF THE

GEOLOGICAL SOCIETY OF LONDON.

EDITED BY

THE ASSISTANT-SECRETARY OF THE GEOLOGICAL SOCIETY.

Quod si cui mortalium cordi et curæ sit non tantum inventis hærere, atque iis uti, sed ad ulteriora penetrare; atque non disputando adversarium, sed opere naturam vincere; denique non belle et probabiliter opinari, sed certo et ostensive scire; tales, tanquam veri scientiarum filii, nobis (si videbitur) se adjungant. —*Novum Organum, Præfatio.*

VOLUME THE FIFTY-SEVENTH.

1901.

LONDON:

LONGMANS, GREEN, AND CO.

PARIS: CHARLES KLINCKSIECK, 11 RUE DE LILLE.

LEIPZIG: T. O. WEIGEL.

SOLD ALSO AT THE APARTMENTS OF THE SOCIETY.

MDCCCCI.

List

OF THE

OFFICERS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

Elected February 15th, 1901.

President.

J. J. H. Teall, Esq., M.A., V.P.R.S.

Vice-Presidents.

J. E. Marr, Esq., M.A., F.R.S.
H. W. Monckton, Esq., F.L.S.
Prof. H. G. Seeley, F.R.S., F.L.S.
W. Whitaker, Esq., B.A., F.R.S.

Secretaries.

R. S. Herries, Esq., M.A.
Prof. W. W. Watts, M.A.

Foreign Secretary.

Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S., F.L.S.

Treasurer.

W. T. Blanford, LL.D., F.R.S.

COUNCIL.

W. T. Blanford, LL.D., F.R.S.
Sir John Evans, K.C.B., D.C.L., LL D., F.R.S., F.L.S.
Prof. E. J. Garwood, M.A.
Prof. T. T. Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A.
R. S. Herries, Esq., M.A.
William Hill, Esq.
W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.
Prof. J. W. Judd, C.B., LL.D., F.R.S.
Lieut.-Gen. C. A. McMahon, F.R.S.
J. E. Marr, Esq., M.A., F.R.S.
Prof. H. A. Miers, M.A., F.R.S.
Right Rev. John Mitchinson, D.D., D.C.L.
H. W. Monckton, Esq., F.L.S.
E. T. Newton, Esq., F.R.S.
G. T. Prior, Esq., M.A.
F. W. Rudler, Esq.
Prof. H. G. Seeley, F.R.S., F.L.S.
Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S.
J. J. H. Teall, Esq., M.A., V.P.R.S.
Prof. W. W. Watts, M.A.
W. Whitaker, Esq., B.A., F.R.S.
H. B. Woodward, Esq., F.R.S.

Assistant-Secretary, Clerk, Librarian, and Curator

L. L. Belinfante, M.Sc.

Assistants in Office, Library, and Museum

W. Rupert Jones.
Clyde H. Black.

TABLE OF CONTENTS.

PROCEEDINGS.

ERRATA.

P. 41—Lines 26–29 from the top *should be read after line 15, the name* 'Whitman Cross' *being substituted for* 'Washington.'
P. 160—Line 33 from the top, *for* 'nearly' *read* 'never.'

LIST OF THE FOSSILS DESCRIBED AND FIGURED IN THIS VOLUME.

Name of Species.	Formation.	Locality.	Page
PLANTÆ.			
Naiadita lanceolata. Figs. 1–3 & pl. xiii	Rhætic	Pylle Hill, Bristol	307–312
CRINOIDEA.			
Pentacrinus basaltiformis (?). Pl. ix, figs. 22 & 23	Lower Lias	Arran	237
ANNELIDA.			
Ditrupa globiceps. Pl. ix, fig. 21	Lower Lias	Arran	237
LAMELLIBRANCHIATA.			
Avicula lanceolata. Pl. ix, fig. 5	Lower Lias	Arran	232
Cardinia Listeri. Pl. ix, figs. 15 & 16	Lower Lias	Arran	235
Cardita Heberti. Pl ix, fig. 11	Lower Lias	Arran	235
Goniomya sp. Pl. ix, fig. 17	Lower Lias	Arran	236
Gryphæa arcuata. Pl. ix, fig. 9	Lower Lias	Arran	233
Lima pectinoides (?). Pl. ix, fig. 7	Lower Lias	Arran	233
—— *succincta.* Pl ix, fig. 8	Lower Lias	Arran	233
Myoconcha psilonoti (?). Pl ix, fig. 10	Lower Lias	Arran	234
Nucula sp.	Lower Lias	Arran	234
Nuculana (Leda) Tatei. Pl. ix, fig. 12	Lower Lias	Arran	234
—— sp. Pl. ix, fig. 13	Lower Lias	Arran	235
Ostrea irregularis (?)	Lower Lias	Arran	233
Pecten (Chlamys) subulatus (?). Pl. ix, fig. 6	Lower Lias	Arran	232
Pholadomya (?). Pl. ix, fig. 19	Lower Lias	Arran	236
Protocardium truncatum (?).	Lower Lias	Arran	236
Tancredia (?) Peachi, sp. nov. Pl. ix, fig. 20	Lower Lias	Arran	236
Unicardium cardioides. Pl. ix, fig. 18	Lower Lias	Arran	236

Name of Species.	Formation.	Locality.	Page
	Gasteropoda.		
Amberleya acuminata. Pl. ix, fig. 2	Lower Lias	Arran	231
Cerithium Semele (?). Pl. ix, fig. 3	Lower Lias	Arran	231
—— sp.	Lower Lias	Arran	231
	Cephalopoda.		
Ammonites (Ægoceras) angulatus. Pl. ix, fig. 1	Lower Lias	Arran	231
	Mammalia.		
Pantholops hundesiensis. Figs. 1 & 2	Upper Pliocene	Hundes (Tibet)	289–92

EXPLANATION OF THE PLATES AND FOLDING-TABLES.

PROCESS-BLOCKS AND OTHER ILLUSTRATIVE FIGURES,

BESIDES THOSE IN THE PLATES.

THE

QUARTERLY JOURNAL

OF

THE GEOLOGICAL SOCIETY OF LONDON.

VOL. LVII.

---

1. ADDITIONAL NOTES *on the* DRIFTS *of the* BALTIC COAST *of* GERMANY.[1] By Prof. T. G. BONNEY, D.Sc., LL.D., F.R.S., F.G.S., and the Rev. EDWIN HILL, M.A., F.G.S. (Read November 7th, 1900.)

CONTENTS.

I. INTRODUCTION.

WE quitted Rügen in 1898 with no expectation of ever seeing it again. But after completing the paper which has appeared in the Society's Quarterly Journal,[2] we felt the usual desire of once more going over the work. When there seemed a possibility of gratifying this, we should have withheld our paper, if a special reason had not existed for an early publication of our views. We determined, however, in 1899 to cover a wider field and to examine not only Arkona (which want of time had prevented us from visiting), but also some sections at Warnemünde which we expected to prove very

[1] This paper was delivered to the Society on May 4th, but as neither author could be present on the only evening then free, the reading was at their request deferred to this Session. In the interval they have had the opportunity of consulting a work by Prof. E. Geinitz, published about 15 years ago, which has been recently added to the Society's Library. A paper by Herr A. Baltzer has also appeared, Zeitschr. d. Deutsch. Geol. Gesellsch. vol. li (1899) p. 556. He considers the folding of the Chalk to be prior to the deposit of the Drifts, but apparently will not exclude the possibility of some folding being produced by the thrust of an ice-sheet. Much of his paper is devoted to the occurrence of drumlins in Jasmund. Most of these occur in the district west of the Chalk-hills, though two or three are situated on them. These we must have seen, but cannot commit ourselves to this view of their origin.

[2] Vol. lv (1899) pp. 305–26.

different from those in the Jasmund district. This was the case, though they were not exactly what we had been led to anticipate.

In looking for papers on Rügen we unfortunately missed a small monograph by Dr. Rudolf Credner ('Rügen: Eine Insel-Studie,' 1893),[1] which would have been very useful as a clear statement of one view and as containing a list of the literature after 1886. He considers that in the Arkona and Jasmund areas (but not universally) the 'Diluvium' is naturally separable into a lower member consisting of two greyish-blue boulder-clays with an intervening bedded sand; and an upper one, of boulder-clays, gravels, and sands, which is unconformable with the other.[2] He regards the boulder-clays as true ground-moraines; the sands and gravels as produced from these by denudation. The dislocations to which he attributes the peculiar association of the Chalk and the Lower Drift were produced after the deposition of the latter, but prior to that of the Upper Drift. In this interval the older one was considerably denuded, which explains its occurrence at the present time only in sheltered places. He maintains that the Chalk has been shattered into a series of blocks which have been thrust one against the other, and bent down irregularly and in many directions: the Diluvium being wedged in among them. As proofs of these movements, he instances the irregular distribution of the Drift-masses, which, for example, are small and narrow from Sassnitz to the Kollicker Bach, broaden out near the Mönchsteig, and between Stubbenkammer and Lohme occupy nearly the whole coast, occurring in like manner near Arkona. Again, in inland quarries the Chalk is often replaced by Drift. The throw of these dislocations measures from some inches to well over 900 feet. Often one block merely sinks against the other without disturbance of bedding, though the latter is also found. In his opinion as many as eleven or twelve such blocks occur between Gakower Ufer and Kollicker Ort. In all cases these dislocations affect only the lower member of the Drift—the two boulder-clays and the intervening sand.

II. The Coast near Warnemünde.

The Drift near Warnemünde has been described by Johnstrup and Geinitz,[3] and again very recently by the latter in a small geological guidebook for Mecklenburg.[4] This contains three photographic

[1] See also 'Forschungen zur Deutschen Landes- u. Volkskunde' vol. vii, pt. v, p. 377.

[2] He states that the total thickness of this Drift varies considerably: in the cliffs of Granitz it is from 30 to 40 metres (98·4 to 131·2 feet), on Hiddensöe 70 metres (229·6 feet), in well-sinkings it ranges from 20 to 60 metres (65·6 to 196·8 feet), and at Quoltitz reaches 96 metres (314·9 feet).

[3] 'Beitrag zur Geologie Mecklenburgs' pts. vi & vii (1884–85). [This work was not in the Society's Library when we wrote, but a copy has now been procured. Pt. vi contains a map of the distribution of the Drifts; pt. vii a panorama of the cliffs, in which, however, the sea appears to have made changes since 1885.]

[4] 'Geologischer Führer durch Mecklenburg' Berlin, 1899.

illustrations of its most remarkable sections; but, as the work is not likely to be generally known, and the only reference to the Warnemünde Drift which we have come across in our own language is liable to be misunderstood, we offer to the Society the results of our examination. In so doing we shall endeavour to avoid theories and describe facts, referring only to the former so far as to point out what is demanded by the latter; for we think that if this plan were more generally followed, better progress would be made in solving the problems presented by the Drifts of Northern Europe.

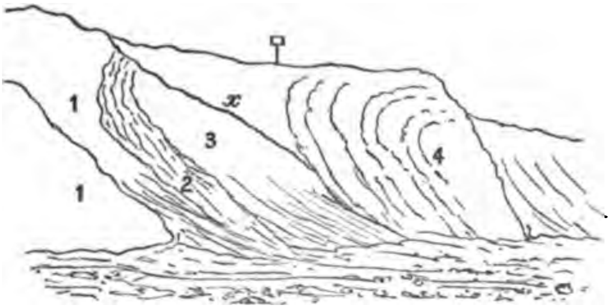
Warnemünde, the port of Rostock and a watering-place on the Baltic, is on the western bank of the mouth of the Warnow. The river on the other side expands into a broad sheet of water, separated from the sea by a peninsular lowland. Beyond it the ground rises a little, but as careful searching with good field-glasses was unpromising, and it is mapped as dunes, we left this without further examination, and confined our attention to the other bank of the Warnow, where we studied the coast between Warnemünde and Heiligendamm, a distance of about 10 miles as the crow flies. This, however, for a considerable extent at each end, is without interest, as a line of very low flattened dunes separates the Baltic from an almost equally level alluvial plain. But in the middle is a gently undulating tract rising from this plain to a maximum elevation of slightly over 60 feet, which is scarped by the waves into cliffs. These extend along the shore for nearly 2 leagues, and usually afford very fair sections of the glacial deposits, which, however, are generally uniform in character: all the more interesting occurring along about 1¼ miles of the coast, and commencing rather more than that distance from Warnemünde.

The results of our examination, we think, will be more readily understood if we begin our description at Heiligendamm, so as to work from west to east.

For some 2 miles east of this place the coast, as intimated, is low, but there is higher ground to the west, which, however, we did not visit as it gave no promise of clear sections. Beyond the dunes the ground gradually rises, forming a cliff which, for a considerable distance, ranges from 2 to 3 yards in height, and consists of a strong, stony, brownish-grey clay. The cliff dies away towards an opening, on the other side of which it again rises, attains a greater elevation, often 4 or 5 yards, and occasionally about twice as much. Here the lower part consists of a clay, not quite identical with that already mentioned. Over it comes a rather sandy band, often only 4 or 5 inches thick, and then a clay, such as we have already seen, which passes up into a sandy soil from 18 inches to 2 feet thick. We will call these clays, for the purpose of reference, the lower and the upper.

The former is grey, and contains the following materials:—(a) Chalk: much of it being in small grains, from the size of a mustard-seed downward; these often are about as common in the matrix as carraway-seeds in a cake. The rock also occurs in pebbles,

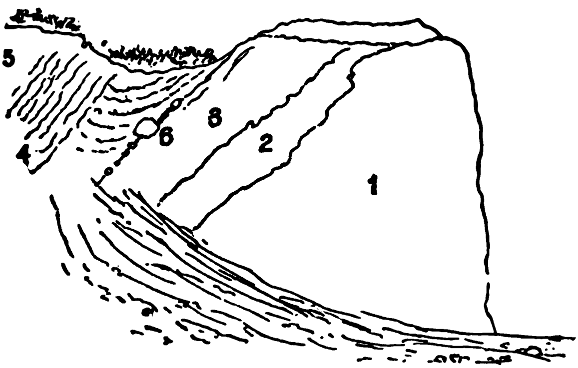
Fig. 1.—*East side of one of the troughs.* *(See p. 5.)*



[The notice-board is at the western end of the wood mentioned in the text.]

1 = Lower boulder-clay.
2 = False-bedded sand.
3 = Upper boulder-clay: behind this at *x* are traces of a beach-like layer.
4 = Sand banded with clay; much bent, as indicated.

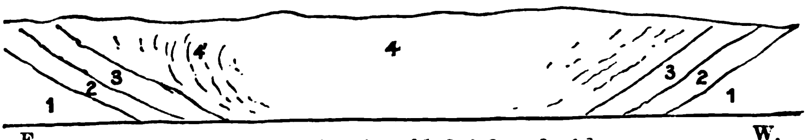
Fig. 2.—*West side of the same trough.*



[For the explanation of 1, 2, & 3 see fig. 1. Beach-like layer below 2.]

4 & 5 = Sand banded with clay, lying as indicated: 5 continues visible, with some contortion, for about 12 feet.
6 = Boulder, measuring about 2½ × 1½ feet in a beach-like layer.

Fig. 3.—*Generalized section of a trough (about 100 yards wide).*



[For the explanation of 1, 2, & 3 see fig. 1.]

4 = Sand banded with clay, more or less contorted, and especially so at 4'.

generally well rounded, which are seldom larger, and usually smaller, than a pigeon's egg: these seemed to us more local in distribution, and to be a little less common in the higher part of the clay. (*b*) Flint: this is less abundant, the fragments varying from fairly rounded to practically unworn; usually they are small, but now and then a block a few inches across may occur. (*c*) 'Scandinavian' rocks, chiefly crystalline and rather dominating in bulk over the flint: these vary in size from a coarse grit to stones, generally well-rounded, of considerable size, specimens some inches in diameter not being rare. We saw two or three boulders of large size actually embedded in the clay, and blocks ranging from 2 to 4 feet across are numerous on the beach. Some of these are smoothed on one side and retain well-marked striations, while a few are facetted. We observed also in the clay two or three boulder-like masses of a rather fine, stratified, clayey gravel, containing numerous small pebbles of chalk with some flint and 'Scandinavian' rocks; possibly also one or two similar masses of sand. This lower clay often reminded us of the Cromer Till and the lowest of the clay-beds in Holderness; occasionally also of parts of the Chalky Boulder-clay in East Anglia.

The upper clay does not differ materially from the lower, so far as the stones are concerned, but its matrix is browner and is more apt to become locally sandy.

The lower clay[1] and the sandy band rise gently eastward, and the latter after a time can be no longer distinguished; but even then the clay in the upper part of the cliffs appears to be more sandy than that in the lower, which maintains a generally uniform character.

This description holds good till we have passed another opening, and are rather more than a league from Warnemünde. Here the cliffs reach their greatest elevation, and the somewhat monotonous uniformity of the sections is locally interrupted by the presence of sandy material, forming slight recesses and occasionally little valleys. The first of these occurs some 150 yards west of the end of the low wood, perhaps ½ league long, which covers this part of the upland—called Stolteraa; another is just under the end; and they are found at intervals—being about ten in all—over a distance of rather more than 1½ miles. (See figs. 1–3, p. 4.) In the intervals the cliff generally is formed of boulder-clay, its lower and larger part being of that described above as the lower one; but the upper 10 feet or so show a more sandy variety, corresponding better with the upper clay farther west. The top of this clay (1) on each side of a recess descends at an angle of some 25°. Above it, with apparent conformity, comes a false-bedded yellowish sand, 4 or 5 feet thick (2); and above this again is another clay (3), also stony, but a little yellower and more sandy than that below. This is overlain by a mass (4) of stratified sand with more clayey layers, which fills the greater part of the trough, and is usually much contorted.

[1] We occasionally saw the lower clay exposed on the beach in shallow water; and it was disclosed less than a mile from Warnemünde, in a cutting made for the foundation of a groyne.

Beneath it, on the top of the second clay, we occasionally find a layer of grit and stones, sometimes subangular, once or twice associated with a boulder a couple of feet in diameter. This layer generally is only a very few inches thick, and closely resembles the material of the present beach. In one or two of the recesses we found traces of a similar layer between the bedded sand and the clay beneath it. Small stones sometimes occur in the sands which occupy the trough, but chiefly if not wholly in the more clayey layers; and in one section a band of very dark laminated clay is present, with numerous small pebbles of chalk, flint, etc. This band is rather jagged in outline, generally about 3 or 4 inches thick, but occasionally more than a foot: these irregularities being probably due to fracture and packing during subsidence. But the deposits in the 'Contorted Drift' seem to show greater variability than the more uniform masses beneath them. In one place two of these recesses are near together, parted only by a 'gable' of the lower clay; and in another, a low mound of this material apparently rises up for some 3 yards above the shore, interrupting the 'Contorted Drifts' near the western end of a trough. But this possibly may not be *in situ*. The larger number of these recesses are to the west of the track leading down from the Wilhelmshöhe restaurant, but three or four lie on the other side of it.

More details could be added, but enough, we think, has been said to bring out the principal features of these interesting sections. The sand (2) clearly overlies the main mass of clay, and the clay (3) comes above it. But whether these correspond with the sandy band and the upper clay in the extensive sections to the west is not easily determined: on the whole we are inclined to suppose them represented by the more sandy part of the main mass (1) in these eastern sections, and regard (2) & (3) as more recent, though underlying the 'Contorted Drift.' This probably once extended over the whole area, whence it has been generally removed by denudation. But how were these troughs formed? It seemed to us impossible that they could be ordinary valleys excavated in the lower boulder-clay in which the beds 2, 3, etc. had been afterwards deposited. The synclinal slope of beds 2 & 3 and the contortions of the overlying bedded sands, in which, however, traces of a similar structure are perceptible, indicate that the mass as a whole has been let down and probably puckered by unequal movements or by packing during that process. Of faulting in the ordinary sense of the term we found no trace, and dismissed that hypothesis as improbable. Still more impossible did it seem to attribute the relations of the Drifts to the action—thrusting, ploughing, or dragging—of an ice-sheet. The structure would more naturally be produced by the gradual removal of material which had once supported these beds nearly in an horizontal position. The Drift, if we rightly understand Prof. Geinitz, is probably very thick, and it rests upon Chalk.[1] We can hardly suppose

[1] The maximum thickness in the district (E. Geinitz, 'Uebersicht über die Geologie Mecklenburgs' § v, 1885, p. 29) is 133 metres. Chalk is shown as cropping out inland near the western end of the Stolteraa.

that subterranean denudation of the latter rock would be locally so intensified as to produce these down-drops in the Drifts; but if pre-existent valleys in the Chalk had been filled up with frozen snow, prior to the deposit of these alternating strata, or if the lower part of the Drift had enclosed tabular berglike masses of ice, which afterwards melted away, such a structure might be produced.[1] Of the two hypotheses, we view the latter with the less favour, but the former also has its own difficulties. We do not, however, see our way to suggesting anything better.

III. Arkona.

The headland of Arkona, above the northern end of Rügen, may be described in general terms as an insular mass of Chalk rising about 200 feet above sea-level, and situated at one corner of a slightly lower plateau of Drifts.[2] But on closer examination we find that it also is capped by Drift, though of a different colour and composition. This is often from 3 to 5 yards thick; but at one place, where the coast is projecting towards the east, it apparently reaches a much greater thickness, for the Chalk-cliff below seems to be only 30 or 40 feet high.[3] It is a light-coloured clayey material, containing numerous flints with some Scandinavian pebbles or boulders, not without a resemblance to the 'whitish boulder-clay' which occurs, among other places, near the Waldhalle.[4] In the cliffs facing eastward, the Chalk can be seen for a space overlain by the ordinary Drift. Its surface at first seems to sink irregularly, though somewhat rapidly southward, perhaps, even to below the sea-level; but the slipped Drift and grassgrown slopes make any precise statement impossible. In about 150 yards, however, the Chalk certainly rises into a kind of ridge, the top of which is not much below the edge of the cliff. After this, so far as we could see, it finally disappears, and the cliffs or slopes are formed of Drift. This bears a general resemblance to the boulder-clays of Jasmund, and reminded us in its general aspect of the masses seen last year near Göhren. In one or two places it was sandy, but whether a tripartite division exists here seemed to us more than doubtful. We were unable to examine the corresponding section on the northern face of the headland, but carefully studied the singular 'inlier' of Drift in the Chalk (seen in the crag near the buildings of the lighthouse) which has been described by Prof. F. Johnstrup.[5] His diagram had suggested

[1] To this view, we infer that Prof. Geinitz, on the whole, inclines.

[2] It was once a stronghold of the Rugii; their earthwork, sometimes over 30 feet high, still remains crossing the headland.

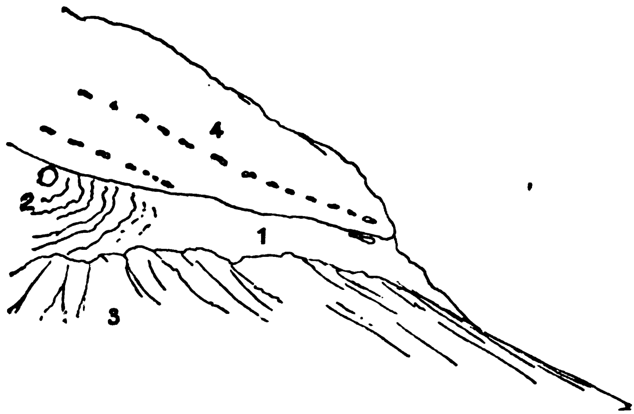
[3] Possibly the other Drift may come in below, but we had not time to attempt a minute examination of this part, if indeed it is accessible, and had to content ourselves with what we could see from the deck of the steamer.

[4] Dr. Credner appears to place both in the 'Ober Diluvium,' Forsch. z. Deutsch. Landes- u. Volkskunde, vol. vii (1893) p. 448. Certainly they appear to be unconformable with the Drifts below, assigned to the 'Unter Diluvium.'

[5] Zeitschr. d. Deutsch. Geol. Gesellsch. vol. xxvi (1874) p. 572. More briefly also by Dr. R. Credner, Forsch. z. Deutsch. Landes- u. Volkskunde, vol. vii (1893) p. 448.

to us the possibility that a great erratic of Chalk rested on clay, like those in the Contorted Drift of Cromer. That, however, is not the case: the Chalk is unquestionably continuous with the main mass, which runs for a considerable distance to the north-west, forming cliffs overlooking the sea. As shown in the appended diagram (fig. 4), the

Fig. 4.—*Chalk and Drift below the Lighthouse station, Arkona.*



1 = Clay, containing on the right a little seam of Chalk about 3 inches thick, and becoming more distinctly laminated and crumpled towards 2, where is a boulder some 15 inches long; about 6 or 7 feet at most exposed in a vertical section.
3 = Slipped clay; a little bedded sand disclosed near the numeral.
4 = Chalk-with-flints.

Chalk seems to overlie the Drift; but, on closer examination, the latter appears more probably to have filled a cavity cut in the former. The upper margin of this cavity, it will be observed, is not quite parallel with the bands of flint. The Drift is mainly a somewhat laminated and banded clay, containing but few stones, though we saw one about 15 inches in diameter. Near the top surface one or two thin films of chalk were interbanded with it. This Drift is much contorted. A few feet are clearly exposed in a nearly vertical section, and then comes a broken slope of slipped material. A little way down the latter, sand is visible; and as this cannot have slipped from above (where there is no Drift) we conclude that it is practically *in situ* at a lower level than the banded clay. For some little distance south-eastward, the slope is in a condition which makes it impossible to say anything about the amount or relations of the Drifts. Only one section is clear, that described above.

Both faulting and the thrust or drag of an ice-sheet seemed to us untenable as explanations of the relations of the Chalk and the Drift. The latter occupies a cavity in the former, in whatever way it may have been introduced. Whether it is now as originally deposited, or has been let down by subsidence, there is no evidence to show. In any case, the apparent inlier of Drift probably is only

a remnant of a much larger mass; and this part of the coast rather nearly corresponds with a pre-Glacial Chalk-cliff, against which the Drift was deposited. The latter has gradually been washed away, and this remnant, which, like one or two instances described by us in Möen, was lodged in a hollow of the Chalk, has alone escaped the waves.

IV. The Jasmund District.

Favoured by magnificent weather we again examined every section near Crampas-Sassnitz, and on the coast between it and Stubbenkammer, not only from above, but also from below; for this time we were able to walk, without any interruption, from one place to the other along the beach. We also made the sea-passage five times. As the steamer keeps near the coast, we found this very helpful, the sections being exhibited in a much truer perspective.[1]

We must apologize for two or three slips in topography. The most serious has been already corrected. It arose from suppressing the wrong pair of sketches in order to reduce the number of illustrations: those left represent a section near the Kollicker Bach instead of near the Waldhalle; and the error, in the revision of the proofs at a busy time, unfortunately passed undetected, for the two sections are much alike. The difference is that in the Kollicker-Ufer section, Drift appears on both sides of a rib of Chalk, but in the Waldhalle section only on one side, and the whitish boulder-clay is more strongly developed in the latter. The description holds equally good, if we strike out the references to the three aiguilles[2] and the words 'east of the Restaurant.' The second slip, as well as a little vagueness regarding one or two other localities, is due to most of our work having been done before we obtained a map on a convenient scale. A section figured on p. 320 (in our previous paper) is described as 'under the Blockhouse at the corner of the forest.' It is about ¼ mile north of this position, which is more nearly that of the 'pocket' of Drift mentioned on the preceding page.

Apart from these we have nothing to withdraw, and are able to make some additions which we think important. We desire at the outset to repeat, if possible in more emphatic terms, that between Rügen and Cromer there is no analogy: the Drift[3] is a local incident in the Chalk, not the Chalk in the Drift. The total outcrops of the Glacial deposits measured near sea-level cannot be more than a tenth, perhaps even less than a twelfth (allowing for slips) of the Cretaceous. The Chalk in these cliffs is as obviously *in situ* as it is in the precipices of Speeton, or in those between Freshwater Gate and the Needles.

The three members of this Drift, as a rule, are only well seen

[1] Beyond Stubbenkammer there seems to be little of interest, but at Lohme Chalk apparently is exposed underneath Drift.

[2] We find that these are called Wissower Klinken.

[3] We refer, of course, to the Tripartite Drift (Unter Diluvium).

when they occupy an (apparent) valley in the Chalk, but the lowest one (clay), at any rate occasionally, can be traced for some distance nearly at the same level at the top of the Chalk-cliff. Probably then the Drift, as a whole, once extended over the plateau from which this cliff has been carved. In these supposed valleys the bedded Drift dips, as a rule, at a considerable angle, from about 20° to nearly 90°,[1] and towards the south, ending abruptly on that side against a rather steep face of Chalk. The surface of the Chalk on which the Drift rests, we may repeat, though commonly it corresponds very nearly with the dip indicated by the bands of flint, not seldom affords instances, both on a large and on a small scale, where the one cuts across the other.

One of the best examples of this occurs at the Gakower Ufer,[2] in which considerable changes had been made (perhaps artificial) since the previous year, as will be seen from a comparison of fig. 5, p. 11, with that given in our former paper. By the removal of 'slip' the general relations of the members of the Drift had been rendered much clearer, enabling us to make the following additions to our former report:—(i) On either side of the Drift the Chalk rises rapidly, and in a short distance forms the whole of the cliff. (ii) The lower clay can be traced almost continuously along the beach for about 180 yards, the outcrop suggesting a slight curve with the ends pointing inland. (iii) On the northern side the Chalk, as we can now see, is slightly undercut by the clay, and the triangular face (not exposed in 1898) is stained, showing that it has been buried under the Drift. (iv) On the same side the overlying sand is very distinct, but seems before long to be cut off or replaced (as shown) by more clayey material; though this possibly may be illusory and the result of slip. (v) The third member (upper clay) appears to be in place, and is followed by a bedded sand. The latter in section suggests an arrangement in a series of conical shells, one of which seems to be 'faced,' over a considerable area, by a layer of coarse gravel, mixed with rounded boulders (Scandinavian rock) occasionally quite 2 feet in diameter, which however apparently dies out towards the east.

This section (we examined it three or four times) is most perplexing. We suspect that just at this part the beds are dipping steeply inland; that the upper as well as the lower 'Diluvium' is present; and the one may not be conformable with the other. Two more observations may prove to be significant: one, that a broad strip of ground behind the edge of the cliff bears the aspect of having slipped seaward; the other, that the sand-pit, in which the beds are nearly vertical (described on p. 312 in our former paper), lies about 300 yards inland from this section.

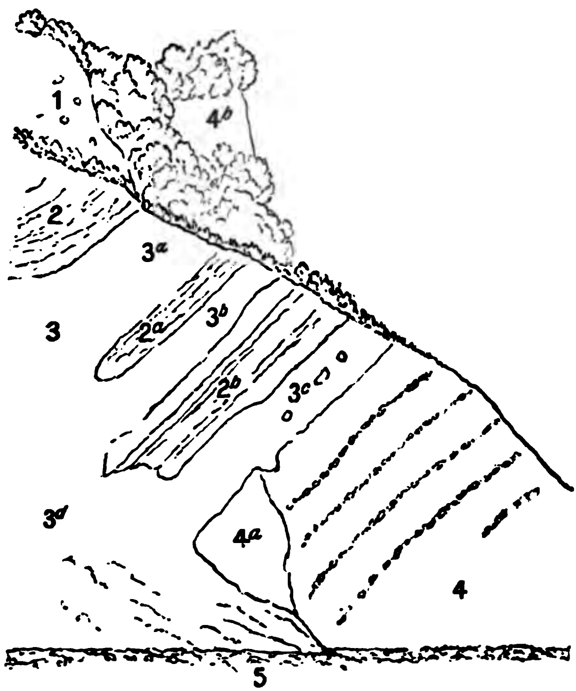
Three facts which we had noticed last year were brought out more distinctly by the views obtained from the sea:—(i) That the

[1] Dr. R. Credner (Forsch. z. Deutsch. Landes- u. Volkskunde, vol. vii, 1893, pp. 392, 452 *et seqq.*) holds that the lower Drift was much denuded before the deposition of the upper.

[2] Figured and described on p. 320 of Quart. Journ. Geol. Soc. vol. lv (1899) as 'under the Blockhouse.'

'inliers' of Drift appear to occupy valleys excavated in the Chalk. (ii) That these valleys can be traced for some distance inland; or, in other words, that the present valleys appear to follow lines of pre-Glacial drainage.[1] (iii) That the steep slopes or walls of Chalk,

Fig. 5.—*Gakower Ufer (as exposed in 1899): northern end of the section.*



[See fig. 8 p. 320 in Quart. Journ. Geol. Soc. vol. lv (1899): erroneously named 'Section under the Blockhouse.' The wall of the recess (6) in it is a small portion of 4 *a* in the present drawing.]

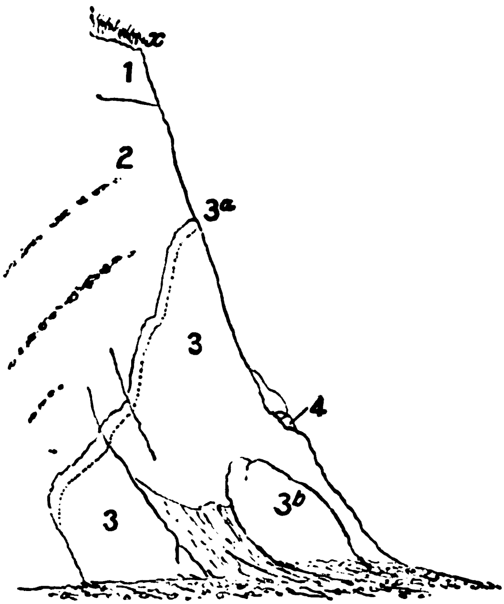
1 = Clay, with boulders.
2 = Bedded sand. 2 *a*=Bedded sand, about 5 feet thick. 2 *b*=Sand, well-laminated, sometimes false-bedded, about 12 feet thick.
3 = Grey clay. 3 *a*=The same. 3 *b*=Sandy clay, about 4 feet thick. 3 *c*=Grey clay with boulders, about 4 feet thick. 3 *d*. Below here much slipping, but the clay can be traced to the beach.
4 = Chalk with bands of flint.
4 *a* = Vertical cliff of Chalk at a high angle with the face of 4, and stained by the clay, which at the bottom still rests against it.
4 *b* = Chalk-cliff, some 30 yards away.
5 = Pebbly beach.
[3 *c* is certainly the 'lower clay;' 2 *b* corresponds, in part at least, with the 'middle sand;' while the 'upper clay' is represented in 3.]

[1] Dr. Credner and those agreeing with him would say 'of faults.'

towards which the Drifts dip sharply and against which they end abruptly (usually on the southern side), often trend gradually inland, as if the present coast-line had passed very obliquely across an old valley.

In one or two instances, we found the Drift to be slightly twisted up against this steep face of Chalk: the most interesting example occurring in a section a short distance north of the Wissower Bach, which last year we missed owing to a difficulty in getting along this part of the coast. On the southern side, the lower clay is slightly dragged up (as shown in the sketch) against the Chalk, which, indeed, is even a little undercut. In a few yards to the north the top part of the clay disappears behind the middle sand, which then lies against the Chalk; and lastly, at a rather higher level, the upper clay takes this position, so that at the northern end we have all three members of the Drift, as they are shown in fig. 7. This section is irreconcilable with the hypothesis of a simultaneous folding of Chalk and Drift. But so are most others, especially the group from the Kieler Bach southward, for which it was specially invented. These sections, as we pointed out in our former paper, indicate a succession in, not a duplication of, the

Fig. 6.—*Section between the Wissower Bach and the Wissower Klinken (southern end).*

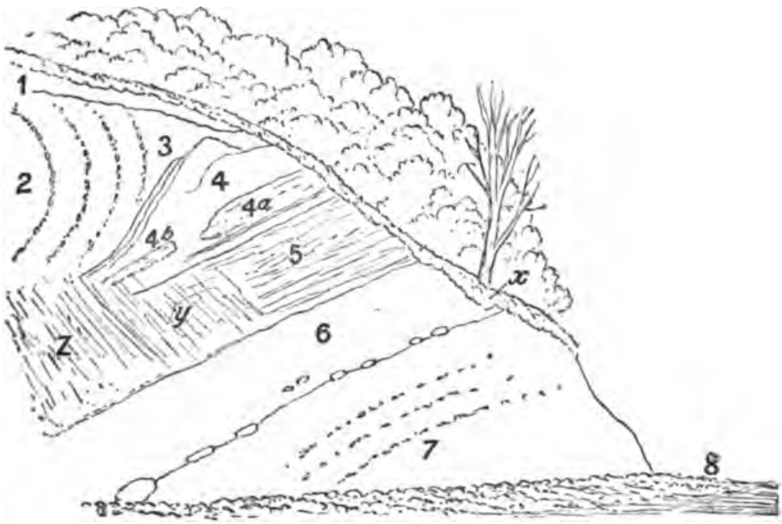


[Taken from a position 7 or 8 yards south of that from which fig. 7 was sketched, and looking more directly at the cliff, so that the other is, so to say, round the corner.]

1 = Whitish boulder-clay—probably rearranged, nearly a yard thick.
2 = Cliff of Chalk, about 2 yards high at the edge; the flint-bands being the outcrop of curved layers which dip somewhat into the cliff.
3 = Grey boulder-clay—the lower mass (No. 6 of fig. 7).
$3a$ = Clay stained brown, about 6 inches.
$3b$ = A slipped lump of the clay.
4 = End of the sand (No. 5 of fig. 7).
x = Pebbly beach.

Drifts. But on re-examination, the impossibilities of the 'folding' hypothesis showed themselves more clearly than ever. After the Kieler Bach the Drift comes three other times down to the beach in (perhaps) a long half-mile. In regard to that section we have nothing to add to our paper, except that we are more than ever certain that on

Fig. 7.—*Section between the Wissower Bach and the Wissower Klinken (northern end).*



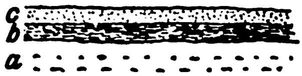
1 = Whitish boulder-clay, or rearranged material from it.
2 = Vertical wall of Chalk ; flint-bands locally curved, cut obliquely.
3 = About 1 foot of banded clay and sand, apparently in a vertical position.
4 = Nearly vertical face of a grey stony clay. 4 *a*, 4 *b* = Bedded sands in the same—possibly only parted by a 'wash-over' of clay ; but if so, the latter band is much thinner than the former.
5 = Variable stratified, sometimes false-bedded, sand, about 10 feet thick.
6 = Grey boulder-clay (the lower mass), very characteristic, with fairly large boulders (Scandinavian) at the base. Nearly 9 feet thick.
7 = Chalk with flint-bands (not clearly displayed). As the sections are not in parallel planes and the curvature in 2 is very local, the discordance in bedding is more apparent than real.
8 = Pebbly beach and sea.
x = Soil and vegetation, about 15 to 18 inches thick, and rather overhanging near the position of the letter.
y = Sand rather obscured by slips.
z = Slope of chalk-rubble.

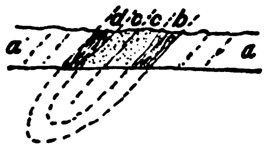
the southern side the Drift rests against an old cliff of Chalk, while on the northern it overlies a sloping surface of the same rock.[1] A short distance south of the Kieler Bach, Drift is seen high up on the cliff apparently filling a shallow valley or basin, but as this spot is

[1] This, on approaching the bottom of a glen, rises in a slight ridge.

inaccessible we merely note the fact as significant. The second descent of Drift to the beach, at a rough estimate, is 400 yards south of the Kieler Bach; a third comes, perhaps, in another 300 yards, followed after an interval by a fourth. The Drifts descend the cliffs obliquely; in the second and third sections they seem to be interstratified with the Chalk, but in the fourth some reddish sand appears (it is rather masked by slip) over part of that rock and the upper clay, while at the top of the cliff the whitish boulder-clay extends over the whole. In all these sections, the lower boulder-clay is fairly constant in thickness, some 18 or 20 feet; so also is the sand (perhaps 15 feet), which exhibits progressive changes upward, showing in two instances at least a seam of gravel at the bottom only; but the upper clay in two sections is much thinner (not much over a third), and in one considerably thicker than the lower clay. It is therefore impossible to consider that these deposits are doubled up. But another grave difficulty exists, which apparently has not struck those who support this hypothesis. The folding, as we can see, must have occurred immediately after the deposit of the older Drifts, which then must have consisted, not of clay, sand, and clay, but of one clay followed by sand. Even if we suppose these to have been frozen, they must have adhered with singular persistency to the Chalk to permit of the beds, shown in the first diagram (fig. 8), being doubled up so neatly (like a closed book) as in the second (fig. 9).

Figs. 8 & 9.—*Diagrammatic sections to illustrate the 'folding hypothesis,' showing the relations of the Chalk* (a) *and the Drift* (b, c) *before and after the doubling-up.*



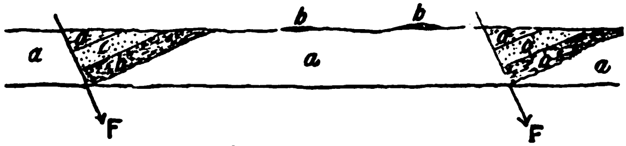


Certain of these sections, at first sight, seem favourable to the hypothesis of faulting. But it also presents serious difficulties, some of which we mentioned in our former paper, while others came out more strongly during our revision. The gravest of these is of a general character. As stated above, we are justified in assuming the Drift to have formerly rested upon the Chalk in a nearly horizontal position. Why, then, do the members of this Drift plunge, as a rule, so sharply and suddenly towards the fault-plane on its downthrow side? The appended diagram (fig. 10, p. 15) will suffice to show the abnormality of the arrangement.[1]

[1] Of course, the difficulty may be got over by making the faults reversed (as is done by Dr. R. Credner at the Kieler Bach), but for this we can find no evidence. [We may refer here to a difficulty raised by a friend after this paper had been read: namely, that as the flint-bands exposed in the cliff appeared generally to have a southerly dip, the Chalk must be extraordinarily thick. But we pointed out in our former paper (p. 306) that the folds in that rock

We again failed to discover any signs of conspicuous faulting in this district. Slight dislocations do occur where the Chalk shows most indications of folding, as in the part nearer Sassnitz, though certainly not in the region of which we have just spoken. But we did find additional evidence of the letting-down of these Drifts into valleys. One we have already mentioned. The Lenzerbach section is another; for in this, when regarded from the sea, the junction-surface of the Chalk and the overlying Drift takes the form of a reversed flattened arch. A section on the Kollicker Ufer, viewed

Fig. 10.—*Diagrammatic section to illustrate the 'faulting hypothesis,' showing the sharp bending-down near the fault-planes which would be needed to bring the beds into their present position.*



Allowing for a reduction in an horizontal, as compared with a vertical, direction, this fairly represents a cliff-section when seen from a distance. a = Chalk; b, c, d = the three members of the Drift; FF = Faults.

in the same way, shows a V-like hollow in the Chalk, ending much above the beach; the lower clay and sand rest on a slope at a moderate angle on the northern side, and seemingly end abruptly against a steep wall of Chalk which could be seen rising behind and above the Drift. Again, in a section some distance to the south-east of Stubbenkammer (a little south of the valley called Mönchsteig) a quantity of Drift fills a hollow in the Chalk, in section like this ◡: the latter rock is continuous for a good height above the beach.[1]

Here the Drift consists not only of the usual three members, but of a thick bed (over 30 feet) of overlying sand followed by a third clay, which is capped (?unconformably) by the usual whitish boulder-clay. On the northern side, the synclinal structure of the beds in the Drifts is very clear; on the southern this is masked by slip and vegetation, but the view from the sea conveyed the impression that it also existed there.

There is, however, yet another instance which had not been disclosed in July 1898. We called special attention[2] to the section

strike nearly due north and south, which is also the general direction of the coast from the Wissower Bach to the Kollicker Ort (approximately). At the former it turns south-south-westward, at the latter approaches the north-west. In both these parts folding becomes very conspicuous. Also we do not deny the existence of faults, but maintain them and the folds to be long anterior to the deposition of the Drift. So we believe, as intimated in our former paper, that, notwithstanding the frequency of an apparently southerly dip, no great thickness of Chalk is exposed in the cliff-sections.]

[1] We made ourselves certain of this fact from below, and also studied the section from above.

[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 315.

exhibited by a pit west of the Crampas-Sassnitz railway-station, because it proved the tripartite Drift to lie on the slope of an old Chalk-hill at a fairly high angle, and the flexures are shown by the flints to have been in existence when that Drift was deposited. In 1899 we found that the pit had been worked back for some distance (on the left-hand side of our diagram), just at the part which the previous year was obscured by mud and chalk-dust. We then called attention to a thickening of the Drift-material on the left of the summit[1] (No. 5 in fig. 3, *op. cit.* p. 315)[2] as 'apparently a filled-up pit.' It was, however, now seen to be something far more important, namely, a head of a shallow Drift-filled valley, of which a fairly good section was exposed. Fig. 11 (p. 17) represents as careful a sketch as we could make (verified by a traverse). Confining our attention for the moment to the Drift, we see that the three members, which on the more eastern side of the hill repose uniformly on a fairly steep slope of Chalk, are here dropped down (at the northern end of the quarry) into a valley some 30 feet deep, bounded on its western side by a slight cliff of Chalk, at the bottom of which an horizontal fissure is exposed, filled partly with clay and partly with sand. The arrangement of the several beds, their distortions and dislocations, more visible in the sand than elsewhere, suggest that they have been let down into the valley from an horizontal position above it. We may add that here also the surface of the Chalk is dipping rather steeply beneath the Drift (that is, away from the spectator), and that no loose unworn flints are anywhere found at the base of the latter. Above the upper clay are clay and gravelly sand; but this part of the section was so much masked by slight slips and 'wash-over' that (as the foreman objected to our lingering here) we will not venture to say more than that the Drift in this, as in some other sections, consists of more than three members.[3] We may add that the Chalk a little to the left is only covered by surface-soil, and no trace of the buried valley can be seen on the hill-slope at the back of the drawing.

We have included in our sketch a little more of the Chalk exposed in the pit-wall, because our former one did not suffice (as we had anticipated it would) to lay the ghost of the 'great ice-plough.' We had endeavoured to make it clear in our last paper that no evidence could be found in Rügen to support this hypothesis, while there was much hostile to it. We shall be ready to

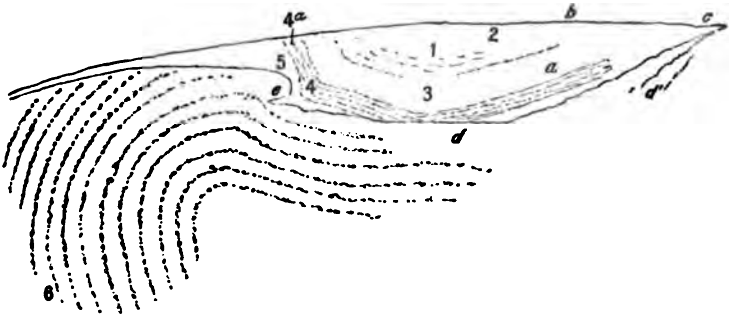
[1] This, according to an aneroid measurement, is about 140 feet above sea-level. The Crampas terrace (R. Credner, Forsch. z. Deutsch. Landes- u. Volkskunde, vol. vii, 1893, p. 429) is nearly 100 feet above sea-level.

[2] This was examined two months later by Herr A. Baltzer (Zeitschr. Deutsch. Geol. Gesellsch. vol. li, 1899, pp. 558, 559 & figs. 2, 3). The latter of these figures corresponds with the upper part of that given in our last paper (*op. cit.* p. 315, fig. 3), but does not show so plainly the tripartite division of the Drift; the former indicates that the working had already been carried back far enough to show the real significance of the 'apparently filled-up pit,' which was quite indeterminate when we saw it; but in 1899 further working had exposed still more, as is represented in our drawing (fig. 11).

[3] Hence, either the Lower 'Diluvium' must sometimes consist of more than three members, or the Upper be also affected by this disturbance.

admit the potency of ice-sheets as excavators, benders and breakers of rock-masses, when any evidence worthy of the name can be produced in proof that they operate in these ways; but, though we have diligently sought for this in the field, we can only find it asserted on paper. Accordingly we feel justified in regarding it as a theory which rests upon an hypothesis. Even if it were true, it

Fig. 11.—*Section in Von Hausemann's Quarry.*



[Compare section in Quart. Journ. Geol. Soc. vol. lv (1899) fig. 3, p. 315. The above figure shows the Drift-filled hollow which begins at 5 in that sketch, and may be regarded as continuing the sketch farther to the left, though the face of the quarry has been worked some distance back.]

The details in the part within *a*, *b*, *c*, and from *d* to all about *d'*, are obscured by 'wash-over' or slipped Drift.

1 = Apparently clay all about here, but much masked, and gravelly sand is seen here and there below.
2 = Sand, gravelly sand, and a reddish clay.
3 = Bluish-grey clay—hardly less than 15 feet thick. (Probably identical with 2 *b* of the former diagram.)
4 = Well bedded sand, about 7 or 8 feet thick. The details at the angle are not quite clear, but there seemed to be fair evidence for its existence. Well bedded sand, like a 'tongue,' can be traced to near the end of the horizontal pipe (*e*), and then comes clay.
4 *a* = Apparently a continuation of this bed of sand, dipping at a high angle. (Probably identical with 3 of the former diagram.)
5 = Clay: the apparent thinning-out is due to its passing at the back of a projecting edge of Chalk. (Probably identical with 2 *a* of the former diagram.)
6 = Chalk-with-flints. Diagrammatic, but accurate in important points. The blank part was not filled in, as that would have merely continued the fold.

From the number 6 to the top is apparently 60 feet. From the top of the Chalk to the surface of the ground in the line of 1 and 3 is perhaps 30 feet.

could not, in our opinion, explain the relation of the Chalk and the Drift in this pit, and the way in which the great curving layers of flint are cut off by the latter. We also find difficulties in understanding how the ice-ram could be brought into action here. The crest of the anticline runs more or less northward, so the thrust has come from an easterly or westerly direction. Now, in the

former, rather higher ground, that of the Stubnitz, stands in the path of the ice-sheet; while the latter (in which direction the ground undulates to the Jasmunder Bodden) is hardly the route which can have been taken by the main mass of ice.

We may more briefly dismiss another hypothesis, started during the discussion (the reasons which we had given for excluding it having been apparently overlooked), namely, that the present singular association of the Drift with the Chalk is due to subterranean denudation of the latter. The Chalk of Rügen contains bands of flint. The latter, indeed, is rather more nodular in character than in the Upper Chalk of England; nevertheless we think we may fairly allow about 3 inches of solid flint to 6 feet of Chalk. To bring the Drift into its present position often requires the removal by solution of 30 to at least 60 feet of Chalk.[1] Thus a band of broken flints should be left (as in England), from some 15 inches to over 2 feet thick. We had been looking out for this band during the whole of our work in 1898; we again searched carefully for it in 1899; and we rarely, if ever, found even a solitary fragment of flint. Yet we saw such fragments in some of the pipes! We think, then, that until that difficulty be removed, that hypothesis needs no further discussion; nor does another form of it, the falling-in of the roof of caves, prove more satisfactory. The absence of Chalk-débris below the Drift, the regularity with which the three members of the latter dip towards the steeper wall of the Chalk, and their uniform arrangement, negative the latter modification of the hypothesis. If, then, neither this, nor ice-thrust, nor folding, nor even faulting, satisfactorily explain the peculiar relations of the Drift and the Chalk in Rügen, we can find none better than that which we offered last year, claiming for this at any rate that it accords with all the facts which we have observed.

In conclusion, we may repeat that we deem ourselves justified, as on the last occasion, in abstaining from further discussion of the agency by which the Drift was deposited. Whether the tripartite Drift were directly laid down by an ice-sheet, or by the intermediate action of water, we should still have to explain how it got into its present abnormal position, and to that point, for good reasons as we think, we have at present restricted ourselves; for it is entirely distinct from the other.

Discussion.

Sir Henry Howorth said that the only claim which he had to enter into the discussion was that he had several times seen the cliffs discussed in the paper from the uncertain vantage of a steamer's deck whence Mr. Hill drew his 'panorama,' and had read the various memoirs which have been published on them by the German geologists. The amount of this literature was much greater, and it went back much farther in time, than was generally supposed; and the speaker

[1] The cliffs in which these drifts are intercalated must often be much higher. Prof. Credner, *op. cit.* p. 429, gives the height of the Waldhalle terrace as 230 feet, and the Wissower Klinken as a few feet higher; so that we deliberately understate our case, and in some instances might even triple the higher figure.

was surprised that so little use of it had been made in England, for with the exception of some references of his own it had been almost entirely overlooked until quite lately. The main conclusion of these memoirs, and also of the symposium of Northern geologists which met at Kiel some years ago, was to emphasize the enormous difficulty of solving the problem in question; and the speaker was not surprised that every one of the explanations which had occurred to the present Authors had been in turn discarded by them, and that we should be left in the same position of doubt as before.

What he felt quite certain of was that the phenomenon could not be treated as a local one, nor could it be explained if we limited our horizon to the small locality of Rügen. As Wahnschaffe and others have shown, it is intimately connected with disturbances that occur in nearly all parts of the North German Plain and (as the speaker believed) with areas a great deal farther off. In these localities, stretching westward as far as the Rhine, the Drift-beds are found intercalated with, and apparently undergoing a common disturbance with, those underlying them. Similar phenomena occur in Schleswig and in Mecklenburg, and very largely in the brown-coal and Middle Tertiary deposits of Northern Germany, as has been shown by the well-sections published by Wahnschaffe, and by many superficial sections elsewhere. The phenomenon is a continental one, and not limited to the islands of Rügen and Möen.

With regard to the introduction of ice or snow as factors in the explanation of this particular difficulty, the speaker said that he would not repeat what he had said elsewhere in papers on the dislocations of the Chalk. He would merely remark, for the benefit of those who are always looking to ice in some form as the explanation of every geological difficulty in the surface-beds, that in this particular case the dynamical problem involves that the ice should have come from two directions at right angles one to the other at the same time, since the stones in the local drift are a mixed collection, partly from Gothland, Œsel, and Esthonia, and partly from the Christiania Fiord. This is one serious nut to crack out of a great many.

Personally, he was greatly delighted that these Baltic beds, which probably contain an answer to difficulties nearer home, should again be attracting attention in England. They were well known to 'the old masters' whom he loved; and he only wished that the Authors of the paper would extend their researches over the much wider field where similar beds were shown many years ago to exist, by the German geological surveyors. He felt certain that nothing but tentative results could follow from generalizing from so local and limited an area as the one described in this and the Authors' previous paper.

The Rev. E. Hill replied that the Authors had extended their researches to Möen in Denmark, Warnemünde in Mecklenburg, and the North German Plain; besides examining all the papers that they could discover. He repeated that the Rügen cliffs were not like those at Cromer, as they were continuous solid Chalk, instead of continuous Drift including isolated boulders of Chalk.

2. *The* GEOLOGY *of* MYNYDD-Y-GARN (ANGLESEY). By CHARLES A. MATLEY, Esq., B.Sc., F.G.S. (Read November 21st, 1900.)

[Map on p. 24.]

CONTENTS.

I. INTRODUCTORY.

ABOVE the village of Llanfair-y'nghornwy, in the north-west of Anglesey, stands a hill known as Mynydd-y-Garn or The Garn. Although rising to a height of less than 600 feet above Ordnance datum, it is one of the highest hills in the county, and is so well elevated above the surrounding country that from its crest the view embraces the greater part of the island, the Caernarvonshire mountains, and large expanses of sea.

Ramsay in his memoir on the 'Geology of North Wales' makes but slight mention of the Garn,[1] merely noting that it lies in a much-faulted district. Prof. Blake gave a brief notice of the geology of the hill in his 'Monian System of Rocks';[2] and the present writer gave, incidentally, a further short account in a recent paper.[3] The results of a more detailed examination of the geological structure made during the past summer seem to warrant a more extended description than any hitherto made.

II. STRATIGRAPHY, AND DESCRIPTION OF THE ROCKS.

The mass of the hill consists of an inlier of sericitic and chloritic schistose phyllites, usually green, surmounted by a massive conglomerate, and surrounded by black slates and shales. The slates, apparently of Upper Llandeilo age, form a strip about a mile in width, and are bounded both on the north-east and south-west by fractures which bring them against older rocks.

A geologist making a traverse from Craig-y-gwynt over the hill in a north-north-westerly direction (see fig. 1, p. 22) and then north-north-eastward to the northern coast, will meet with the under-mentioned rocks in the following order:—

1. Black Slates (with an anticline of grit at Craig-y-gwynt).
2. Green breccias, with partings of black shale.
3. Gnarled green phyllites.
4. Green, bluish, and brown phyllites and fine grits, less fissile than the preceding and but little gnarled.

---

[1] Mem. Geol. Surv. 2nd ed. (1881) p. 246.
[2] Quart. Journ. Geol. Soc. vol. xliv (1888) p. 473.
[3] *Ibid.* vol. lv (1899) pp. 649–50, also p. 676.

5. Garn Breccia, Grit, and Conglomerate.
6. Black Slates with courses of grit and breccia.
7. Black Slates without grit-courses, but with layers of tough mudstone.
8. Llanfair-y'nghornwy Beds.
9. Green Series of Northern Anglesey.

As the traverse follows the direction of dip there is apparently an upward succession all the way; the Black Slates and grit of Craig-y-gwynt seem to be at the base, and the rocks of the Green Series of the Northern District at the top. The true sequence of the rocks is, however, quite different from this apparent order.

The following descriptions should be read in connection with the map (fig. 2, p. 24). It will be most convenient to commence with the green phyllites at the southern end of the hill.

Garn Phyllites.

These are mostly green rocks of fine grain, apparently once shales intercalated with gritty layers (sometimes sufficiently differentiated to form flaggy bands); but they are now sericitic and chloritic phyllites, often well though minutely foliated, and usually containing clastic material. In their lower part they are almost exclusively green, though in one spot near Nant, close to where they are faulted against Black Slates, some purple zones appear in them. At the southern part of the hill they are picturesquely contorted, and are indeed as highly 'gnarled' (Hughes) as in the better-known area east of Amlwch. Though the crumpling has usually been effected with very slight disruption, the rock is occasionally found to have been brecciated in the process. The 'gnarling' appears to be of later date than the foliation, and seems to be the result of post-Llandeilo movement.

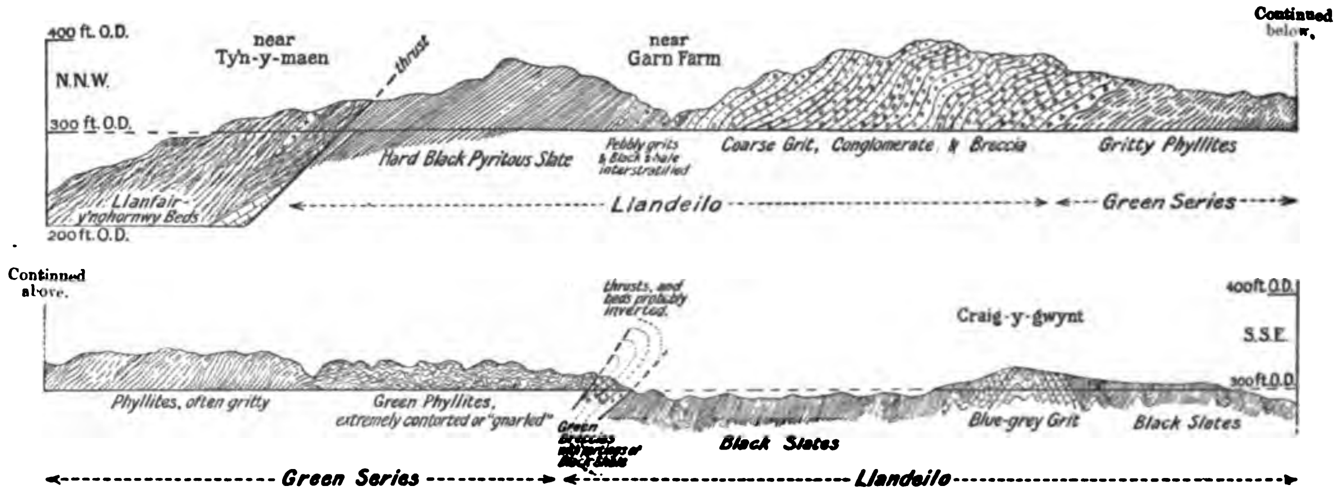
The contortions become less pronounced northward, and die out; the green phyllites give place to rocks which are less distinctly green, being more often bluish or brown. They consist of compact phyllites and fine grits, and as a rule are less fissile than those just described. The dips are northerly, or veer between north-north-west and north-north-east, and measure from 45° to 80°; but the planes which determine the dip are perhaps cleavage- or shear-planes, and may not represent true bedding, for the structures of these phyllites when examined under the microscope are seen to be largely secondary, the result of dynamic action. Three microscopic sections [N.A. 138, 139, & 140 [1]] have been sliced from these rocks and all exhibit brecciation *in situ*, slide N.A. 140 having the character of a thrust-conglomerate.

The green gnarled rocks are easily correlated with beds of the Green Series of the Northern District of Anglesey, and the upper beds must also be grouped as part of the same series.

These phyllites are cut off to the west and south by a strongly curved fault which brings them against Black Slates on the west,

[1] The numbers in square brackets are those of the slides in my cabinet.

Fig. 1.—*Section across Mynydd-y-Garn, west of (and subparallel to) the Garn-Castell Fault.*



[Length of section=about 1 mile. The vertical scale=twice the horizontal scale.]

and against green breccias on the south. This fault is readily traceable on the ground; and though its plane cannot actually be seen, it is most probably a thrust-fault, on account of the intense contortions of the green phyllites, and because the green breccias appear to be inverted and to pass below the phyllites.

Garn Conglomerate, Grit, and Breccia.

This formation is perhaps 400 feet thick: its base rests upon the phyllites, and it passes upward into Black Slates. Its main outcrop crosses the summit of the hill, and forms a band divided into two portions by a transverse fault (the Garn-Castell Fault).

In addition, on the north-west, near Pen-mynydd, its upper portion is seen, caught in between faults; and at the opposite extremity of the hill, near Cefn-du-mawr, its upper zones are once more exposed, represented by green breccias.

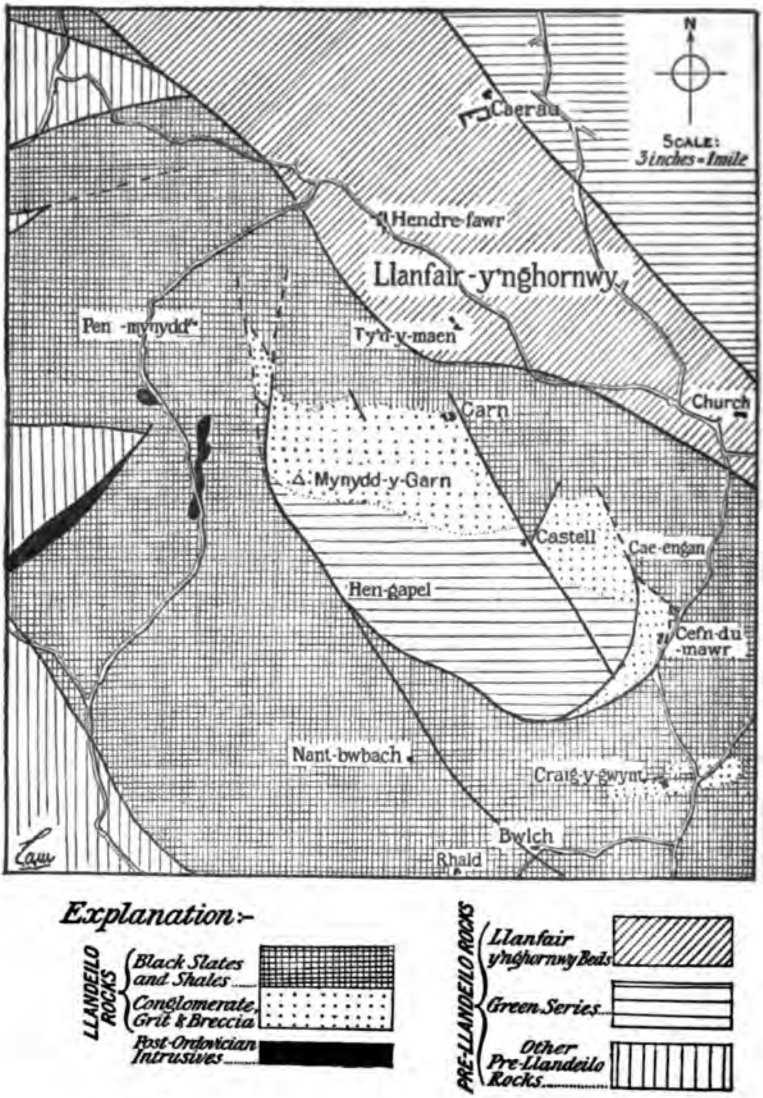
The formation is sometimes a coarse angular breccia, sometimes a conglomerate with pebbles fairly well rounded, often a grit with or without pebbles. In its north-western part the fragments are commonly of quartz and grit, and of quartzose, schistose, gneissose, and granitic rocks. To the south-east, towards Cae-engan, pieces of green phyllite are very abundant. Rocks corresponding to the former are found *in situ* near Mynachdy, 1½ miles to the north, and at Pen Bryn-yr-Eglwys, 2 miles to the north-west; while the pebbles of green phyllite agree precisely with the rocks of the inlier, and show conclusively that the latter were in their present condition of alteration before the deposition of the conglomerate.

The Garn Conglomerate has approximately the same strike and dip as the underlying phyllites, and it therefore presents in the field a false appearance of conformity with them; an illusion which is only dispelled by the evidence of the contained pebbles mentioned above. The conglomerate is often crushed and coarsely cleaved, and its bedding is sometimes obscure. Its dip is northerly and north-easterly, at angles varying from 20° to 75° or 80°. Its highest beds contain some layers of black shale, and a transition-zone of black shales with courses of grit and breccia intervenes between it and the Black Slates.

The green breccias at the southern end of the hill which are faulted against or overthrust by the green phyllites, represent the uppermost part of the conglomerate. They dip towards the phyllites, and contain bands of black shale. They are made up almost wholly of angular pieces of green phyllite,[1] and in places are almost indistinguishable from brecciated portions of the phyllites themselves. These breccias are thought to be inverted because they apparently pass d o w n into black shale, whereas the sequence on the east side of the hill shows that the black shales lie a b o v e the breccias.

[1] See Quart. Journ. Geol. Soc. vol. lv (1899) p. 676: note on microscope-slide N.A. 53.

Fig. 2.—*Geological map of Mynydd-y-Garn and the surrounding area.*



There is sufficient evidence to show that the rock-sheet of which the Garn Conglomerate forms part was once of fairly wide extent; and its frequent absence from the edges of the Black-Slate areas is the result of faulting and not due to lack of deposition. Portions of it are met with on the eastern slope of Pen Bryn-yr-Eglwys,[1] 2 miles to the north-west; at Porth Padrig near Mynachdy in the same neighbourhood, where it contains fossiliferous limestone-nodules[2]; and at Clymwr,[3] 4 miles to the south-east, whence it has been traced for some miles southward. The conglomerates and grits of Northern Anglesey are, in all likelihood, parts of this same rock-sheet.[4]

The Garn Conglomerate is inferred to be of Llandeilo age, partly because it lies immediately below Black Slates containing Upper Llandeilo fossils, and also because it can be correlated with neighbouring conglomerates of Llandeilo age.

Several microscopic sections have been examined, and they bear out the descriptions just given. Crushing and shearing are observable in most of them. A small well-rounded pebble obtained from the Conglomerate near Cae-engan was sliced [N.A. 141] and was found to consist of rock-fragments of schistose grits, etc. embedded in a slaty matrix. The schistose area from which this pebble obtained its fragments must have been of considerable antiquity, because it is clearly separated in age by two strong unconformities from the Llandeilo conglomerate.[5]

Black Slates and Shales.

On the north-eastern slopes of the Garn these contain at their base bands of grit and breccia, which connect them with the underlying Conglomerate. The beds above this transition-zone are black laminated shales with courses of hard black unlaminated mudstone. About 600 feet in all of these rocks is here seen; they dip steadily north-eastward at angles of 35° to 45°, and are suddenly terminated on the lower slopes of the hill by an overthrust of the Llanfair-y'nghornwy Beds, near which they are usually quartz-veined and very pyritous.

South of the Garn inlier they are black or dark-blue slates of a rather uniform and monotonous character, and their strike follows the general curvature of the boundary-thrust. The dips, often wavy, are high, averaging about 70°, and usually are northerly, though southerly dips occur. These dips may sometimes be merely

[1] Quart. Journ. Geol. Soc. vol. xliv (1888) p. 474.
[2] *Ibid.* vol. lv (1899) p. 647. [3] *Ibid.* vol. xl (1884) p. 571.
[4] *Ibid.* vol. lvi (1900) pp. 234 *et seqq.*
[5] Compare also the occurrence of schistose and gneissose fragments in the Green Series grit of Llanfechell (Bonney, Quart. Journ. Geol. Soc. vol. xxxvii, 1881, pp. 234–35, and Watts, *ibid.* vol. lv, 1899, p. 676). The evidence derived from this pebble supports Mr. Greenly's interpretation of the coast-section at Careg-Onen in the eastern corner of Anglesey, that below the Ordovician rocks of the island there are two older groups of rocks unconformable one to the other and to the Ordovician (Quart. Journ. Geol. Soc. vol. lii, 1896, p. 620).

cleavage, but in many cases they certainly correspond with the bedding. The slates appear to be thrown into a number of steep folds. On the south and south-west they are faulted against older rocks.

At Craig-y-gwynt (the 'Telegraph Station' of the old Ordnance Survey map) a compound anticline of hard bluish-grey quartzose grit, whose base is not exposed, appears below the slates and passes up into them. The conclusion seems to be a safe one that this grit represents the top of the Garn Conglomerate and the passage-beds to the Black Slates; but it must be admitted that, although it resembles lithologically the top zone of the Conglomerate near Pen-mynydd, it differs strikingly in general character and in the nature of its inclusions from the green breccias of Cefn-du-mawr, now less than ¼ mile distant. It would seem that the angular green phyllite-fragments were distributed over a very limited area of deposition.

Oolitic Ironstone.

A fault runs along the western side of Mynydd-y-Garn in a south-easterly direction across the Black Slates. On the western side of this fault, in a field between Nant-bwbach and Rhald, are two exposures of a rock crowded with oolitic and a few pisolitic grains, which closely resembles the Penterfyn oolitic ironstone of Northern Anglesey.[1]

In the more southerly exposure it is a black oolitic ironstone or ferruginous mudstone, which passes upward into soft blue-black shale and downward into fine grit. About 8 or 9 feet of it contains oolitic grains, and there may be more oolitic rock concealed below the grit. The beds dip steadily north-westward at an angle of 58°.

In the second exposure, 100 yards away to the north, the beds dip in the opposite direction, namely, south-eastward, at 20° to 30°. The oolitic rock is flaggy, and passes upward into grey grits that resemble the bottom beds of the exposure just described. It thus appears that the grit lies between two bands of ironstone.[2]

The zone appears to be not less than 20 feet thick. Unfortunately its base is not exposed. Black shales dip towards it as if to pass below it, but they may be cut off from it by faulting. The presence of grit suggests that its horizon is at or near the base of the Black Slates, which is also the horizon of the oolitic ironstone of the northern coast of Anglesey; but if this be so, the rock should also occur on the slopes of Mynydd-y-Garn in the zone above the Conglomerate, where I have not found it. It is to be hoped that more outcrops of this interesting rock will be discovered, and that its horizon will be definitely settled.

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 236.

[2] Mr. J. H. Stansbie, B.Sc., of the Birmingham Municipal Technical School, was good enough to make a rough assay of one of my specimens. He found in it about 28 per cent. of iron.

Llanfair-y'nghornwy Beds.

Between the Green Series of the Northern District and the Black Slates of the northern and eastern slopes of Mynydd-y-Garn intervenes a group of rocks consisting of green, blue, and brown gritty slates and phyllites, with layers and nodules of grit, and beds of grit, quartzite, and limestone. For convenience of description I style them the Llanfair-y'nghornwy Beds, as the village of that name is built upon them. In a quarry near the church they are exposed as green slaty rocks (phyllites), and they there lie upon the Black Slates and appear to dip conformably with the latter, but there is no passage between the two kinds of rock, which are crushed at the junction. The junction, in fact, forms part of the great thrust-fault which sweeps in a curve through Llaufflewin in one direction to the sea at Porth y Corwgl, and in the opposite direction in a sinuous line to the sea at Porth yr Ebol.[1]

Near the thrust the rocks are often broken, crushed, and sheared; the structure is usually phacoidal, and coarser and harder portions of rock are broken up and involved in the finer and more slaty—the structure, in short, is frequently that of a crush-conglomerate. Good examples of these effects of pressure-action are to be found on and around the farm of Ty'n-y-maen, where the weathered surfaces of the beds have a conglomeratic aspect. In these broken beds occurs a thick band of limestone, which has no visible outcrop but was met with, close to the thrust-plane, in a 'level' driven through these rocks; and irregular masses of quartzite of the 'quartz-knob' type also lie in them. A thick bed of the same kind of quartzite can be traced at intervals from Llanfair-y'nghornwy Church in a north-westerly direction to Hendre-fawr; and similar quartzites are again exposed near Mynachdy, where there is also an intrusion of granite.

The Llanfair-y'nghornwy Beds are cut off on the west by the Porth yr Ebol thrust, and on the east by the fault which brings the rocks of the Green Series against them. For some distance these dislocations have a parallel course, but they converge southward and meet south-east of Llanfair-y'nghornwy Church.

From the beds of quartzite and limestone that they contain, the Llanfair-y'nghornwy Beds may be correlated with the rocks of the Llanbadrig Series of the northern coast; and they probably lie at or near the base of that Series, for as a whole they resemble more particularly the rocks along the southern border of the 'Northern Complex,' where the present writer has sometimes felt that the boundary between the Green and Llanbadrig Series has been rather arbitrarily drawn.

Some of the Llanfair-y'nghornwy Beds also resemble the rocks under the Conglomerate very closely, both in the field and under the microscope.

[1] See description in Quart. Journ. Geol. Soc. vol. lv (1899) p. 645. The present map shows that the fault does not fork at Caerau, as I there stated, but at a point south-east of Llanfair-y'nghornwy Church.

III. Fossils.

The few fossils that have been discovered have all been collected from the Black-Slate zones. The zone of interbedded grits and slates above the Garn Conglomerate has yielded none near the Garn itself; but similar rocks are exposed a few miles away to the south-east, in a quarry near Llanbabo Church referred to by Dr. Callaway,[1] and I there collected *Lingula* sp. (common), and the following graptolites :—*Diplograptus teretiusculus* (common), *Leptograptus* cf. *validus*, and possibly, though doubtfully, *Climacograptus* sp. These have been identified by Miss E. M. R. Wood, who remarks that 'the age of the beds as determined by the graptolites is Upper Llandeilo, about the age of the *Cænograptus*-beds. Prof. Lapworth has also examined these specimens.'

At Bwlch, south of Mynydd-y-Garn, in the Black Slates without grits, I obtained a single graptolite—*Leptograptus*, probably the same species as above.

Distant ¼ mile from Bwlch is the oolitic rock already described, which contains an occasional horny brachiopod :—*Lingula* or *Siphonotreta (?)*, *Acrotreta* sp. (brachial valve only).

IV. Earth-Movements in the District around Mynydd-y-Garn.

The region around Mynydd-y-Garn has been affected since Llandeilo times by earth-movements acting from two directions. This is easily inferred by studying the strike of the rocks and the trend of the faults; for both faults and strikes fall readily into two groups, according as they run more or less (1) eastward or (2) south-eastward. About 5 miles south-east of the Garn a third movement has produced a third system of faults and bedding-strikes, which run north-eastward. This last-mentioned movement, which has affected the largest part of Anglesey, has not been studied by me, as it has produced but slight effects in the area under notice.

The easterly strike is the result of a powerful movement acting from the north. All the country west of the Garn and away to Carmel Head has felt its effects markedly. At Carmel Head green phyllites with broken beds of quartzite and limestone have been driven over Llandeilo Slates[2]; while, farther south, Llandeilo Slates and older rocks alternate with and are dovetailed into each other in augen-like outcrops, the Llandeilo Beds tailing out to the west, the older rocks to the east. The rocks are faulted, overthrust, cleaved, crushed, and shattered, and, with the exception of the Llandeilo Slates, are largely in the condition of crush-conglomerates. The boundaries between the rock-groups are sometimes fault-dykes.

The south-easterly strikes have been produced by movement acting from the north-east, and its effects are best seen at Llanfair-y'nghornwy and in the country lying north-west and south-east of

[1] Quart. Journ. Geol. Soc. vol. xl (1884) p. 580.
[2] *Ibid.* vol. lv (1899) p. 646.

that village. The crushing and thrusting that have resulted in this area have been already described in the foregoing pages. In the tract south-west of the Garn the principal faults still have this south-easterly course; but at and near the southern end of the hill the bending of the faults and the curvature of the strike suggest that the movement from the north-east has been combined with a movement from some other direction, perhaps from the north.

V. Summary.

The stratigraphical study of Mynydd-y-Garn and its neighbourhood yields the following results:—

(1) There are three groups of rocks, whose descending order is as follows:

C. Llandeilo, comprising the Garn Conglomerate, Grit, and Breccia, which passes up gradually into Black Slates.

(Unconformity.)

B. Llanfair-y'nghornwy Beds, correlated with part (probably the lowest part) of the Llanbadrig Series of Northern Anglesey.

A. Garn Phyllites, correlated with part of the Green Series of Northern Anglesey.

(2) The rocks are much compressed, crushed, and faulted, and the apparent order suggested by the dips is quite different from the true sequence. The Garn Phyllites have apparently been pushed over the Llandeilo rocks; the latter are also overthrust by the Llanfair-y'nghornwy Beds, and these in their turn by the Green Series of Northern Anglesey.

(3) An oolitic rock is found in the Black Slates in the neighbourhood of the hill, but the evidence is at present insufficient to correlate its horizon with that of the similar oolitic ironstone of the northern coast of Anglesey.

(4) In the country to the west and north-west of the hill the rocks have been extensively crushed by earth-movement acting from the north, and the pre-Llandeilo rocks are largely in the condition of crush-conglomerates.

(5) Around the Garn itself and east of it the principal direction of movement has been from the north-east; south of the hill the structure is perhaps the result of the interference of these two movements.

In conclusion, I wish to express my indebtedness to Prof. Watts, M.A., Sec.G.S., for having again examined my rock-sections and for permitting me to incorporate the results of his examination in my paper; also to Miss E. M. R. Wood and Prof. Lapworth, F.R.S., for kindly identifying the graptolites.

Discussion.

The Rev. J. F. Blake said that he was familiar with the ground described by the Author, and had no criticism to offer on his conclusions. The most interesting feature appeared to be the existence

of an isolated mass almost everywhere bounded by faults. The difference also of the breccia-conglomerate here from the pebbly conglomerate a little farther north is very remarkable. Much of the older rocks hereabouts and to the south are breccias; some of them are crush-breccias, which are local; but most are originally eruptive, though squeezed later. The speaker thought that the pisolites here would be found to represent a definite horizon, like those in the Lleyn and near Bettws Garmon.

Prof. WATTS also spoke.

The AUTHOR thought that very little reply was needed. The pisolitic iron-ore of the mainland of Wales, according to the text-books, is of Arenig age, while the oolitic ironstone of the northern part of Anglesey is assignable to the Llandeilo.

3. *On some* Tufaceous Rhyolitic Rocks *from* Dufton Pike (Westmorland). By Frank Rutley, Esq., F.G.S. *With* Analyses *by* Philip Holland, Esq., F.I.C., F.C.S. (Read November 21st, 1900.)

[Plate I.]

The specimens which form the subject of this paper were selected for examination on account of their peculiar appearance, and because it was thought probable that they might afford some evidence of solfataric action on British rhyolites of considerable geological age. Through the kindness of my friend Mr. H. B. Woodward, F.R.S., I have been able to learn a few particulars concerning the geology of Dufton Pike. From these it appears that the central portion of the Pike consists of volcanic rocks of the Borrowdale Series, bounded by four faults, those on the east and west being approximately parallel and running in a north-north-westerly direction. The rocks faulted against this central mass of volcanic rocks are of Lower Silurian age on the north, south, and east; while those on the west are Upper Silurian, consisting of Stockdale Shales and Coniston Flags.

The specimens about to be described were collected by the late Prof. A. H. Green, F.R.S., and Mr. J. G. Goodchild, F.G.S., and were evidently procured from the Borrowdale Volcanic Series which constitutes the central mass of Dufton Pike. The specimens were given to me many years ago, so that, never having visited that part of Westmorland, I am ignorant of the precise spots from which they were derived. The chief interest which attaches to them lies in the peculiar character of the alteration that they have undergone: an alteration which appears to me to have been probably due to solfataric action.

For the careful analyses which accompany this paper I am indebted to the kindness of my friend Mr. Philip Holland, F.I.C., F.C.S., and for some admirable photographs to Mr. F. Chapman, A.L.S., F.R.M.S. The rock from the northern end of Dufton Pike appeared at first sight to be very like one previously described by Mr. Harker, but further examination leads to the belief that it differs therefrom considerably in some respects.

The following is a description of these rocks:—

No. 1. Northern end of Dufton Pike.—A pale brownish rock, with some darker brown specks and diminutive colourless crystals which have a vitreous lustre. The cut surface shows minute greyish-white specks and a few small irregular veinings.

A section of this rock, when examined in ordinary transmitted light under the microscope, shows a nearly colourless to brownish-yellow groundmass, containing numerous porphyritic crystals and fragments of felspar, most of them in a more or less altered condition, and crystals which for the most part give square or approximately square sections. The latter are generally opaque and of quite microscopic dimensions, so that when examined in

reflected light under low powers it is difficult to say more than that some of them are dark or even black, while others are opaque and white. Since, by this means of illumination, none of the former display any brassy colour or lustre, they may probably be regarded as magnetite, while the latter are evidently pseudomorphs of a white substance, possibly replacing crystals of spinel or garnet.

Throughout the groundmass occur a great number of apparently circular, dusty-looking, brownish to brownish-green spots, averaging about $\frac{1}{500}$ inch in diameter (Pl. I, fig. 1); but occasionally they are elliptical, or appear to have been drawn out in the direction of the rather obscure fluxion-banding. In polarized light these spots undergo extinction between crossed nicols, and are seen to be small fragments of crystals surrounded by a narrow isotropic border of the groundmass (Pl. I, fig. 6). The fragments scarcely ever exhibit any definite crystal-form; but some of them may here and there be found which show what is apparently the edge of a crystal, and sometimes obscure traces of cleavage parallel to that edge. Selecting such examples, it is found that the extinction-angle made to this edge is sometimes 0°, but very frequently about 37° or more: the mean of half a dozen measurements gave an angle of 37° to 40°. The mineral may be regarded as augite. It shows no appreciable pleochroism, and in some instances the fragments exhibit indications that the obscure traces of cleavage intersect nearly at a right angle. The nuclei of some of the small spots apparently consist of fragments of felspar, and in some cases chlorite may possibly be present. It does not seem that the spots are in any way due to the infilling of very small vesicles, but rather that the diminutive fragments represent a shower of volcanic dust incorporated with the lava.

The porphyritic crystals and fragments of felspar are sometimes comparatively little changed, but the majority are partly or wholly represented by alteration-products. The larger porphyritic crystals are in some cases orthoclase; in others, judging from their extinction-angles, they are oligoclase and andesine. In some instances they have been partly or wholly replaced by muscovite (Pl. I, fig. 1). This figure also shows the spotted character of the groundmass or devitrified glass.

In other cases the crystals have been so greatly corroded that they no longer exhibit any definite crystal-boundaries, but merely form irregularly-shaped, spongy-looking patches which may be regarded as greatly altered and highly corroded vestiges of felspar-crystals. See Pl. I, fig. 2, where a patch in the upper right quadrant is in a position of extinction, while other similar patches are brightly illuminated. Occasionally these irregular patches are connected by strings of the same substance or lie in close proximity (as in Pl. I, fig. 3), when it is possible, from their simultaneous extinction, to see that they form portions of the same original crystal, of which they are now mere vestiges.

From this it would appear that these crystals were derived from an earlier source than the less corroded felspars in the rock. Whether their corrosion is due to fusion in the rock in which they

now lie, or to solution by hydrothermal causes, seems to be an open question; but it appears more probable that it may be attributed to a slowly dissolving solfataric action. This view is favoured by the presence of a small amount of opal-silica, which has been demonstrated by the staining of certain spots in an uncovered section of the same rock by treatment with malachite-green, and the permanence of the stains after the section had been washed in hot alcohol. The spongy-looking fragments, above mentioned, have a very fine granular structure which renders them readily distinguishable from the other porphyritic crystals in this rock. Carbonates are present to a trifling extent: an uncovered section, when treated with dilute hydrochloric acid, effervescing chiefly around the margins of included crystals and fragments.

Here and there clear, colourless streaks, which are rarely persistent for more than short distances, may be seen to lie in the groundmass. In some cases they apparently constitute bands following the general direction of the fluxion-banding. They consist for the most part of quartz, with slightly translucent brownish or reddish-brown crystals; also opaque white pseudomorphs with approximately square sections, which may possibly have been spinel or garnet, but it is difficult to form any decided opinion upon this point. There are also small opaque black octahedra, which are no doubt minute crystals of magnetite. Possibly a small amount of ilmenite may have been present; but, if so, it is now altered to leucoxene, and evidence upon this subject is unsatisfactory: the analysis of the rock shows, however, a small amount of titanic acid, only 0·45 per cent.

The rock occasionally contains a few crystals, which in ordinary light are clear, colourless, and in some sections appear as elongated prisms with sharply-defined transverse cleavages; while in what appear to be basal sections of the same mineral the cleavages intersect at right-angles. I think that this mineral is possibly scapolite. It is, however, only an exceptional accessory.

Taking the whole of the evidence afforded by the microscopic examination of this rock, it may be regarded as a tufaceous rhyolite. Its very exceptional spotted groundmass is due to the inclusion of volcanic ejectamenta, mainly as a rather coarse dust, consisting chiefly of augitic, mingled with felspathic material, which has, to a considerable extent, undergone alteration. Small fragments of other rock, possibly of an andesitic character, but too much altered to permit of precise determination, may also be detected. These lapilli constitute a very small proportion of the rock.

The great alteration of many of the porphyritic felspars; the corrosion of what appear to be felspars derived from an earlier source; the pseudomorphic nature of many of the smaller crystals in the rock; the presence of a small amount of opal-silica, indicated by the staining produced by malachite-green; and the general appearance of a disintegration of crystals by solution, rather than by fusion; all seem to point to solfataric action as the chief cause of the changes which this rock has undergone.

According to the analysis made by Mr. Philip Holland (see p. 36), the rock may be regarded as having the composition of a soda-rhyolite. Its tufaceous character, although scarcely perceptible in the hand-specimen, is sufficiently demonstrated under the microscope.

The specimen was given to me many years ago by my former colleague, Mr. J. G. Goodchild, who (I believe), from field-evidence, considered that it was probably a tufaceous rock. That he was right in this surmise is sufficiently clear. Whatever construction be put upon it, it is certainly a very peculiar rock, and one upon which a variety of discrepant opinions might be given.

No. 2. Dufton Pike.—A very compact, pale bluish-grey to brownish-grey rock, with a few darker grey and blackish-green specks. The specimen has a somewhat uneven platy structure, which on transverse fracture gives an irregularly 'stepped' aspect to the broken surface.

Under the microscope the section appears, in ordinary transmitted light, to consist of a pale yellowish to colourless substance: this might be mistaken for a groundmass filled with small colourless rods, which on further examination can be proved not to be microlites. Numerous less translucent, granular-looking patches occur throughout the nearly colourless matter. These are most irregular in form, and their outlines are suggestive of little shreds cut from an ordinary bath-sponge. This brown substance constitutes apparently less than one-half of the rock. The nearly colourless substance really consists of small fragments of altered felspar, while the smaller proportion of brown matter lies between the often closely-packed fragments, and is the groundmass in which they are embedded. Apart from the fragments, of which the rock is mainly composed, a few crystals and fragments of felspars, apparently oligoclase and andesine, are seen in this section, but they are usually too much altered to admit of precise determination. There are also some irregularly-shaped, opaque spots, visible here and there, which in reflected light are seen to be snow-white. They are doubtless leucoxene in most cases, since the analysis of the rock shows the presence of 0·47 per cent. of titanic acid. If the leucoxene be the result of an alteration of ilmenite, that alteration must have been complete, since no trace of unaltered ilmenite is to be seen in the section, nor do these white opaque bodies exhibit any definite crystal-boundaries.

The entire section is seen, both in transmitted and in reflected light, to be traversed by an excessively delicate streaking, the lines being too fine to be described as banding. They pass quite indiscriminately through matrix and fragments, a circumstance which shows that, if due to fluxion, that fluxion must have resulted from reheating of the rock after its consolidation. It seems more probable, however, that this streakiness has been superinduced by solfataric action. Igneous fusion and the accompanying motion of a fused mass would scarcely have permitted the delicate structure of the altered felspar-fragments (later to be described) to have escaped injury, if not disintegration, through any such movement, and it seems more reasonable to attribute the delicate streaking to hydrothermal agency.

In polarized light, the few clearly recognizable crystals and portions of crystals of felspar are, as already stated, apparently to be referred to oligoclase and andesine; but, with regard to the more highly altered fragments which chiefly constitute the rock, still less can be affirmed with any confidence, since a definite boundary indicative of an idiomorphic crystal, other than a ragged and approximately straight line, can rarely be discovered to form part of the boundary of one of these fragments or lapilli. When, however, such a boundary does occur, it is often found to lie at 0° to approximately 21° with the direction of maximum extinction, so that it seems probable that these fragments may in many cases be referred to orthoclase. Some of them, moreover, show indications of twinning on what looks like the Carlsbad type.

The most remarkable feature about these fragments is that they appear to consist of a meshwork of small, colourless rods, lying apparently in any direction and intersecting at any angle. That these rods are not individual crystals is proved by the fact that, in each separate fragment, all the rods undergo simultaneous extinction between crossed nicols. It is evident, then, that they all belong to one and the same crystal. Each of these fragments, therefore, represents not only the breaking-up of a crystal into fragments, but the partial erosion of that fragment both superficially and internally (Pl. I, figs. 4 & 5).

There is one, and, so far as I can ascertain, only one, fragment in this section that affords clear proof of the foregoing statement. It is a rudely triangular fragment of unaltered felspar, which is seen to pass into a mesh of reticulating rods (Pl. I, fig. 7). Both the fresh felspar and portions of its adherent mesh extinguish simultaneously, thus proving that the meshwork of rods and the unaltered fragment of felspar are parts of the same fragment, the whole having originally formed part of one crystal. The little rodlike bodies which constitute the mesh, partly fringing and continuous with the fragment of felspar, have apparently the same refraction and other characters as the felspar-fragment from which they proceed. Why the felspar has been removed from the spaces lying between these small intersecting rods is a matter which I leave others to decide. The removal of the felspar could scarcely have taken place along planes of more ready solubility, because the interbacular spaces are for the most part small triangular or polygonal areas; yet that some kind of selective solution has caused this peculiar honeycombing of the felspar-fragments seems an unavoidable conclusion. The matrix or ground-mass in which these fragments are embedded appears dark during all stages of rotation between crossed nicols; and, when tested with a Klein's plate, scarcely any perceptible difference in the uniformity of the tint is to be observed, except that here and there a few minute birefringent specks may be discerned. When, however, this practically isotropic matter is examined in ordinary transmitted light, it is seen to be crowded with globulites and little rods like those which constitute the altered felspar-fragments, except that, as a rule, they show no double refraction. Without the aid of polarized light it is, therefore, difficult to distinguish the altered fragments from the matrix in which they lie; but in those parts of the

section which exhibit a brown colour in ordinary transmitted light the globulites are more densely packed, and where these cumulitic aggregates occur we may easily recognize them as portions of the nearly isotropic matrix.

As already mentioned, the fine streaky markings cut through both the matrix and the meshes of the altered felspar-fragments, the latter causing no deflection of the streaks. It is, therefore, clear that the streaks cannot be indicative of the fluxion of a lava. The rock may possibly have been a vitreous lava, freighted with a preponderance of felspathic lapilli and dust. This seems indeed to be the case, since the rock partakes more of the character of a tuff than of a lava. It appears that solfataric action is mainly accountable for its present condition.

No. 3. Dufton Pike.—This specimen was given to me by the late Prof. A. H. Green, F.R.S., and in general appearance so closely resembles the rock last described that it seemed quite likely that it would present the same microscopic characters. This supposition is fully borne out by an examination of the section; therefore the foregoing description of No. 2 applies equally well to No. 3, except that in the latter the fragments are somewhat less densely packed, save along a few irregular lines.

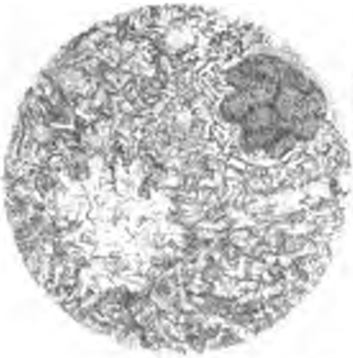
The following are Mr. Philip Holland's analyses:—

ANALYSES OF ROCKS FROM DUFTON PIKE.

	I. Per cent.	II. Per cent.
SiO_2	69·00 1·150	71·05 1·184
TiO_2	·45	·47
Al_2O_3	16·88 ·165	15·36 ·150
Fe_2O_3	·88 ·005	·70 ·004
FeO	—	·66 ·009
MnO	not sought	trace
CaO	1·04 ·018	·29 ·005
BaO	not sought	·11
MgO	·02	·25 ·006
K_2O	3·88 ·041	6·18 ·065
Na_2O	4·64 ·074	3·24 ·052
CO_2*. Combined water, and matter not determined	3·21	1·69
	100·00	100·00

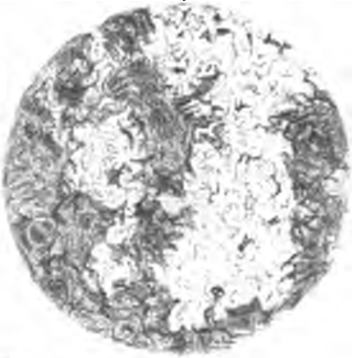
* Carbon-dioxide was detected in both rocks, and, for equal weights of the powdered rock, the effervescence noticeable on moistening with hydrochloric acid was much more marked in No. I than in No. II. The small figures represent the molecular ratios for the percentages beneath which they are placed.

2.

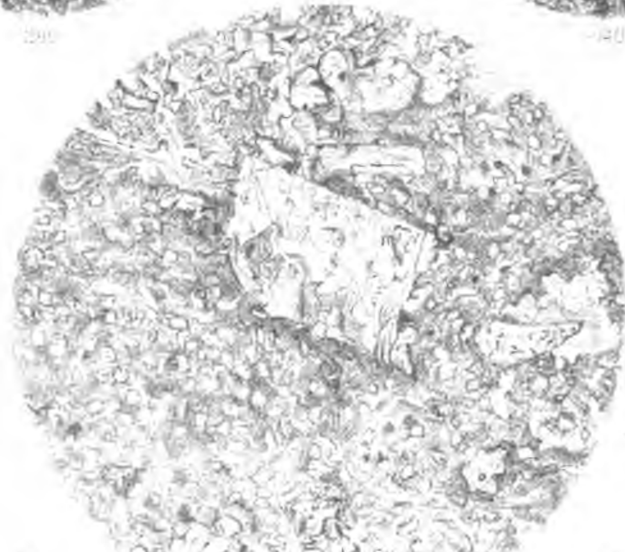


6

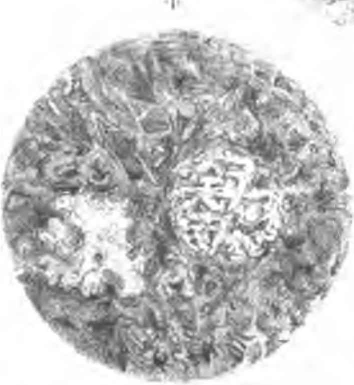
3



1



4

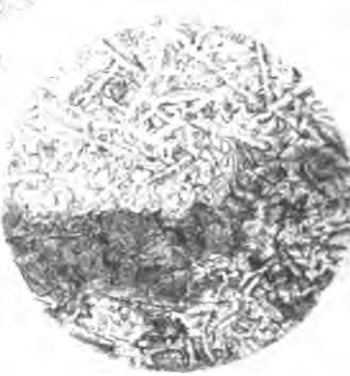


X 140

7

X 200

5.



X 140

Frank Rutley del. M. P. Parker lith. Mintern Bros imp.

TUFACEOUS RHYOLITES FROM DUFTON PIKE, WESTMORLAND.

The Brögger diagrams constructed from the molecular ratios of these rocks correspond so closely with those of rhyolite (=Dufton Pike No. 2) and soda-rhyolite (=Dufton Pike No. 1) that it is needless to reproduce them, since such diagrams accompany the paper by Prof. W. H. Hobbs, entitled 'Suggestions regarding the Classification of the Igneous Rocks,' published in the Chicago 'Journal of Geology,' vol. viii (1900) p. 1.

It is singular that so tufaceous a rock as Dufton Pike No. 2 should be practically identical in chemical composition with a rhyolite; but this coincidence may no doubt be, in a large measure, accounted for by the almost exclusively felspathic nature of the lapilli and dust which constitute so large a proportion of the rock. I have been unable, so far, to locate the small amount of baryta (=0·11 per cent.) shown by analysis to be present in this rock. It may be present among the felspathic constituents in the form of hyalophane, or it may exist as witherite, barytocalcite, or barytes; but the last surmise appears improbable, since the presence of sulphur is not indicated in the analysis.

EXPLANATION OF PLATE I.

Fig. 1. Dufton Pike No. 1.—Altered tufaceous rhyolite of Lower Silurian age showing very numerous spots in the partly devitrified groundmass. The spots are in most cases augitic, in others apparently felspathic fragments of extremely small dimensions. The partly corroded crystals and fragments of much larger size are felspar, sometimes orthoclase, at others oligoclase or andesine. In the centre of the figure is a crystal of orthoclase mainly altered into muscovite. × 30. Nicols crossed. (See p. 32.)

2. Dufton Pike No. 1.—Fragments of corroded felspar, that in the right upper quadrant being in a position of extinction. × 380. Nicols crossed. (See p. 32.)

3. Dufton Pike No. 1.—Vestiges of much corroded and altered felspars. All of these patches, with the exception of that just appearing on the right edge of the figure, undergo simultaneous extinction, so that they are parts of one crystal. × 140. Nicols crossed. (See p. 32.)

4. Dufton Pike No. 2.—Altered and highly tufaceous rhyolite. Small fragments of felspar in a partly vitreous groundmass: that on the right being represented by small rods of unaltered felspar which extinguish simultaneously; that on the left shows very slight traces of such erosion. × 140. Nicols crossed. (See p. 35.)

5. Dufton Pike No. 2.—Similar but larger fragments of felspar in the same section as that represented in fig. 4. × 140. Nicols crossed. Such fragments constitute fully one half of the rock. (See p. 35.)

The following figures are drawn from microphotographs made by Mr. F. Chapman, A.L.S., F.R.M.S.:—

Fig. 6. Dufton Pike No. 1.—Showing a spotted part of the same section as that represented in fig. 1. Here some of the diminutive fragments, mostly pyroxenic or felspathic, are seen to constitute the nuclei of the spots. × 200. Ordinary transmitted light. (See p. 32.)

7. Dufton Pike No. 2.—Showing portion of a small fragment of unattacked felspar, whence proceed small rods of precisely the same character as the mesh-like fragments (fig. 5) which constitute a very large proportion of this rock. The photograph was taken in the position of maximum illumination between crossed nicols. On rotation, the fragment of felspar and the mesh of rods proceeding from it undergo simultaneous extinction. × 200. (See p. 35.)

4. A Monchiquite *from* Mount Girnar, Junagarh (Kathiawar).

By John William Evans, D.Sc., LL.B., F.G.S. (Read November 21st, 1900.)

[Plate II.]

Contents.

I. Monchiquites and their Isotropic Groundmass.

The term monchiquite is now recognized as the designation of a rock, consisting mainly of ferromagnesian silicates in an isotropic groundmass, which has approximately the chemical composition and specific gravity of analcime.

The name was given in 1890 by Hunter & Rosenbusch [10][1] to a rock occurring in narrow dykes, near Cabo Frio in the Serra de Tingua and elsewhere in Brazil, and containing pyroxene, soda-hornblende, mica, and olivine-phenocrysts in a colourless—or, rarely, transparent brown—matrix. This material, which they assumed to be a glass, contains numerous microlites of the porphyritic minerals and, when in a fresh condition, is completely isotropic. It has a specific gravity of 2·31. In a few cases nepheline and, rather more frequently, a felspar with twin lamellation occur. The groundmass is very subject to alteration, natrolite and analcime being formed [20] p. 539 & [24] p. 233. In one instance fluidal structure was noticed to be present. The rock was distinguished from camptonite on account of its glassy base, and received the name of monchiquite, as L. van Werveke had described a similar rock from the Serra de Monchique in Southern Portugal [7].[2]

Rocks with a groundmass of the same character, but without olivine, have been reported from Bohemia by Bořicky [4, 5] and Hibsch [15]. Nepheline [5] p. 176, and leucite [15] p. 99, are sometimes present. J. R. Williams [11] described similar rocks from Arkansas, in which he believed a glassy base had once existed but had since become devitrified.[3] J. F. Kemp found rocks of this class in the

[1] The numbers in square brackets throughout this paper refer to the Bibliography, § VII, p. 52.

[2] In this case the glasslike groundmass showed greyish-blue interference-colours under crossed nicols, and was described as nepheline.

[3] He proposed to separate the varieties without olivine, under the names of fourchite for those containing amphibole and pyroxene, and ouachitite for those containing biotite. But Rosenbusch does not consider olivine an essential constituent [20] p. 545 & [24] p. 233, and in any case the new names appear to be unnecessary.

same district, in which an undecomposed isotropic matrix still exists [11] p. 395; and Kemp & Marsters have described similar rocks from the Lake Champlain region [13].

In 1896 Mr. L. V. Pirsson, of the United States Geological Survey, advanced the contention that the supposed glassy matrix of the monchiquites consisted in fact of analcime. He had been investigating rocks of this class in Montana, and at first accepted the view that they consisted of ferromagnesian silicates in a glassy base [19]; but

'when the rocks were studied in connection with their geological mode of occurrence, it became a source of perplexity as to why such basic magmas . . . should have formed so much glass,'

while the more acid types which accompany them do not, under similar conditions, present glassy forms.

Optical methods failed to yield any decisive results as to the real nature of the supposed glass, and reference was made to the chemical composition of the rock as shown by the analyses. After allowing for the chemical constituents of the minerals known to be present, the remaining silica and the alkalies, alumina, and water were found to correspond with the formula of analcime as nearly as could be expected, taking into account the fact that the composition of the ferromagnesian silicates was not exactly known.

The analysis of the isotropic matrix in the monchiquites described by Hunter & Rosenbusch was dealt with in a similar manner. The iron, lime, and magnesia, as well as the silica needed to form bisilicates with them, were removed; and the proportions of the remainder of the silica and of the alumina, alkali, and water were found to be those of analcime:—

'It has the exact chemical composition, the exact specific gravity,[1] the property of gelatinizing with acids, and the optical properties of analcite; and must therefore be that mineral, and not a pitchstone-glass, as had formerly been supposed' [19] pp. 682–83.

Pirsson further states that in the original Brazilian monchiquite

'the analcite often shows a tendency to crystal-form by the production of areas which are free from the larger prisms of the ferromagnesian minerals, the latter being arranged around them in wreaths. The areas thus resemble phenocrysts of leucite, and they are in reality phenocrysts of analcite. They are sprinkled full of the microlites of hornblende described by Rosenbusch, which do not, however, show any tendency to the zonal arrangement shown by such inclusions in leucite.'

He considers the analcime to be primary, because of the fresh unaltered character of the minerals (*op. cit.* p. 686), and has difficulty in understanding how the base could have undergone a thorough chemical change and decomposition without the minerals being affected in the slightest degree, especially the olivine.

[1] The specific gravity of analcime varies between 2·15 and 2·28, which is less than that (2·31) of the base of the type-monchiquite; but the latter contains microlites of heavier minerals. It is, however, not necessary that a glass of the same composition as analcime should have a different specific gravity.

More recently, Mr. G. T. Prior [21] has noted the occurrence of rocks of the monchiquite-type on Fernando Noronha, associated with the well-known alkali-magma rocks of that island. They are very similar to the Bohemian rocks. The colourless groundmass is isotropic, except in one case when it feebly depolarizes. He defers his decision as to its real nature.

In an interesting paper published in the present year, Mr. John S. Flett has described dykes from the Orkneys, which are very similar to the Brazilian monchiquites [27]. He believes that the colourless matrix, which in this case has a slight action upon polarized light, is a glass which readily passes into analcime and other zeolites (*op. cit.* p. 890).

The question of the true nature of the monchiquite-groundmass has also been discussed by Prof. Lœwinson-Lessing [26] pp. 291–94, who suggests that, if it be analcime, it may be the result of the hydration of an original glass.

II. Analcime as a Rock-forming Mineral.

Attention was first drawn to the importance of analcime as a rock-constituent by Tschermak, in his paper on the teschenites of Moravia, where he describes it as intergrown with felspar in a granular mixture, and sometimes amounting to as much as 27 per cent. of the rock [2 & 3].[1] Rohrbach described it in the same rock as without definite outlines, and filling the interspaces between other minerals [8].[2]

Opinions have differed as to the origin of the analcime of the teschenites. H. Möhl believed that analcime and natrolite were formed by the decomposition of a glassy matrix [6]. Rohrbach and Zirkel consider that analcime is an alteration-product of plagioclase [8, 14], while Rosenbusch would derive it from nepheline [12] p. 332 & [20] p. 279.[3] I cannot find a suggestion that it was in any case an original constituent. In some instances it is undoubtedly secondary, but it seems quite possible that when it is intergrown with felspar or forms the groundmass it may be original. If this be so, the rock may be regarded as an altered variety of the monchiquites, with which it agrees in chemical composition, except that it contains a little more water.

In 1890 Lindgren [9] described an 'analcite-basalt' from the Highwood Mountains (Montana), containing augite, analcime, olivine, and magnetite-phenocrysts in a fine-grained matrix of augite, analcime, and magnetite. The analcime has definite crystalline boundaries, and occasionally shows double refraction. He believed it to be original, because the other minerals (including olivine) are in so fresh a condition. In 1897 Mr. Whitman Cross reported

[1] It was first reported from these rocks by Glocker [1] in 1852.

[2] A similar rock with interstitial analcime has also been described from California [16] p. 284 & [17] p. 27. See also [31] p. 191.

[3] See also [11] pp. 66, 78–79, [16] pp. 284–89, & [17] pp. 27–29.

another 'analcite-basalt' from Colorado [22]. The rock contains, besides augite, olivine, and magnetite, a 'considerable amount of a colourless and isotropic substance both in large and small grains' without crystalline form. The groundmass consists of small grains of the material in question and of augite, magnetite, and felspar. Further, we are told that:

'The larger grains are almost wholly free from inclusions. While probably the last substance to crystallize, the isotropic mineral has pushed back the smaller grains of augite and magnetite, so that they often form a distinct zone about it.' [1]

The fracture is irregular. Becke's method showed its index of refraction to be less than that of Canada balsam. It was separated and analysed (see p. 47), and has approximately the composition of analcime. The low proportion of silica in this analysis is attributed to the probable presence of nepheline among the felspar.

An 'analcite-tinguaite' from Essex County (Massachusetts) has been described as follows by Mr. H. S. Washington [23]:

'The clear colourless micro-groundmass . . . . is holocrystalline, and composed of nepheline and analcite . . . . The patches of analcite are readily distinguished by their cubic cleavage, exhibited by well-defined straight cracks crossing at right angles, by their generally isotropic character, and by the fact that their refractive index is notably lower than that of the felspars. In places they show a very faint double-refraction analogous to that of leucite, but not so well marked. . . . The analcite areas are rather poorer [in inclusions] than those of nepheline.'

This rock is said not to be associated with nepheline-rocks, and Mr. Washington does not believe that it differs appreciably in chemical composition from an ordinary basalt, except by the presence of water.

The three rocks last referred to ought not, I think, to be included among the monchiquites, as in them the isotropic material does not form the groundmass of the rock. It seems clear that it is in each case a primary constituent.

III. A Rock with a Monchiquite-Matrix, from Mount Girnar. (See Pl. II.)

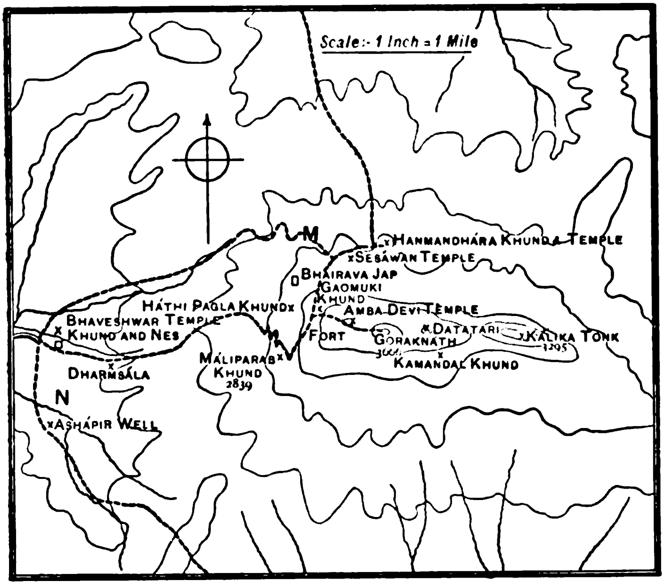
I now proceed to give a brief description of a rock which presents many points of resemblance to the monchiquite-type. In the year 1893 and the earlier months of 1894, I was engaged in a geological survey of the State of Junagarh in Kathiawar, and soon recognized the occurrence of nepheline-syenite in the small isolated mountain-

[1] While no crystalline form was observed, rings or wreaths of small inclusions were noticed in a few grains, and these so strongly suggested leucite that, until the chemical analysis had been completed, he thought that the rock was a leucite-basalt. Occasionally the grains have a smoky tinge, and in a few cases the colouring-matter is arranged in zones clearly suggesting a crystalline form. Leucite also has been found (in missourite) in 'formless masses filling the interspaces between other minerals.' It is 'perfectly clear and free from all inclusions, except now and then a grain of the ferromagnesian minerals.' [30]

group of Girnar.[1] I took specimens, but have only recently had leisure to study them in the laboratory.[2]

The rock, which is the subject of the present paper, is closely associated with the nepheline-syenite, and is met with on the north-western shoulder of the central ridge of Girnar (which runs east and west). It is easily accessible from the small steps on the comparatively little-used route up the mountain which, starting like the main ascent, at the end of the carriage-road from the city of Junagarh, turns off at once to the left, and passes round to the north of the rock known as the Bhairâva Jâp.

Sketch-map of the central ridge of Mount Girnar.



M = Monchiquite. - - - - - = Footpaths.
N = Nepheline-syenite, containing isotropic material in the interstices of the other minerals.
Note.—'Khund' means a spring or pool; 'nes,' a forest-hamlet.

The central mountain consists of a mica-augite-diorite, passing peripherally into an olivine-gabbro which occupies the lower ground. These rocks are at many points penetrated, and sometimes broken up, by dykes rich in alkalies, apparently of nearly the

[1] This lies immediately east of the city of Junagarh, and must not be confounded with the hills of the Gir Forest, which extend over a wide area in the east of the State.

[2] I have to acknowledge the facilities afforded to me by Prof. Judd at the Royal College of Science, and the kindness of Prof. Bonney in arranging for the chemical analysis of rock-specimens.

same age as the diorite; among these is the rock described in the following pages. It occurs on the margin of a nepheline-syenite containing very little ferromagnesian material.[1] In hand-specimens it is fine-grained, and deep black except for numerous white specks.

On examination under the microscope, the small white spots are seen to be colourless spaces, which are as a rule accurately circular and evidently sections of spheres. In most cases they are free from any of the darker constituents of the rock, though now and then a small crystal of hornblende is visible, or a long prism of the same mineral projects into the colourless area.[2] The mineral composition of these spaces differs from point to point, and will be dealt with later.

Outside these colourless areas are abundant crystals of a slightly greenish-brown hornblende; some of the darker crystals, that have a slightly reddish tint, resemble the soda-hornblende barkevikite. They are of all dimensions, from minute microlites up to 1 millimetre or more in length. Common green hornblende is occasionally found.

A pale-green non-pleochroic augite occurs in much less quantity than the hornblende, and is the only important constituent that shows a likeness to any of the minerals of the diorite. It is sometimes found in comparatively large crystals, approaching 1 millimetre in length. These show occasionally terminal patches of dark-green pleochroic ægirine-augite in crystalline continuity.[3] In other cases it forms the nucleus of a brown hornblende, likewise in crystalline continuity.[4] The augite also occurs in small grains either disseminated through the rock or, more frequently, collected in glomeroporphyritic masses, usually irregular in outline, but in some cases showing definite rectilinear contours with angles that suggest pseudomorphs after hornblende.

Biotite is very rare, only one or two occurrences being noted in a large number of microsections. Sphene is fairly common.

A few small granular crystals of an apparently uniaxial mineral with a high refractive index, but very low double-refraction, were seen in one of the irregularly-shaped colourless areas. It may possibly belong to the eudialyte-eucolite group. It is of a pale yellow colour, like some of the eudialytes from Kangerdluardsuk (Western Greenland); but, so far as could be ascertained by the examination of these small grains in convergent light, the sign was negative, as in eucolite, not positive as in eudialyte.

The interspaces between the coloured constituents are filled with colourless material, which will now be described in conjunction with that filling the circular areas.

[1] Other portions of this rock are composed almost entirely of small grains of nepheline, which occasionally show the parallelism of flow-structure.

[2] Occasionally similar spaces with irregular boundaries are seen. These are sometimes due to the coalescence of two spheres: not infrequently they contain coloured minerals.

[3] The angle $\mathfrak{c}:c$ appears to measure about 60°.

[4] In one case a twinned augite was seen to be surrounded by a twinned hornblende having the same plane of composition.

In portions of the rock (including in some cases the greater part of a microscope-section) both the circular areas and the interspaces consist of a colourless isotropic substance of low refractive index. It has no definite boundaries, and is quite continuous, without any indication of break to mark the circumference of the circles. These are defined only by the brown hornblende and the augite that surround them, and occasional grains of nepheline which play the same part as the coloured minerals. Between these the clear isotropic material passes out, and fills the interstices of the coloured minerals. The whole has a curious resemblance to a lake nearly covered with floating vegetation, between which and in occasional open spaces the clear water is visible. (See Pl. II, fig. 1.)

In other places both interspaces and circular areas are made up of anisotropic crystals. Nepheline—sometimes dark in all positions between crossed nicols—is the chief constituent, but a variable amount of orthoclase is also present. A felspar with very fine twin-lamellation is occasionally seen, but not in sufficient numbers for determination: it is not improbably anorthoclase (soda-microcline). Microperthite can sometimes be recognized. The felspar occurs most frequently in the interspaces, while in the open circular areas there is nearly always an excess of nepheline.

Elsewhere, while the interstices between the coloured minerals contain orthoclase and nepheline, the larger circular spaces are either entirely isotropic or partly so, and in part filled with nepheline or orthoclase[1]; but even in the former case the isotropic material does not show definite crystal-outlines. In the case of one area only where the anisotropic crystals were collected round the margin, their inner (apparently idiomorphic) borders seemed to give a regular polygonal shape to the isotropic space in the centre.

This isotropic substance is in some places decomposed into small colourless rod-like crystals, with parallel extinction and interference-colours ranging from white to red and even blue of the first order. The cleavage is parallel to the length.[2] The vibrations in this direction have the greatest velocity of transmission; and if the crystal were uniaxial, and this were the direction of the axis, the sign would be negative. This appeared to be confirmed by examination in convergent light, so far as the minute size of the crystals would permit. The mineral is probably cancrinite,[3] and in this case it has every appearance of being an alteration-product. The presence of cancrinite would explain the evolution of gas, presumably carbon-dioxide, when the powdered rock is treated with acid. The nepheline, too, occasionally contains specks showing higher interference-colours, which probably indicate incipient alteration to cancrinite.

[1] In some cases idiomorphic nepheline is surrounded by the isotropic base.

[2] The terminations are not well-defined, and an indistinct transverse jointing, which is not always exactly at right angles to the length, may sometimes be observed.

[3] See [11] pp. 79, 80. The comparatively low interference-colours are explained by the fact that the crystals are usually too small to occupy the whole thickness of the section.

In some of the circular colourless areas seen in microscope-sections a considerable, irregularly-bounded portion, or even the whole, is broken up into cloudy ill-defined patches with interference-colours varying from white to red of the first order. The crystals are usually cloudy, from the presence of innumerable minute, often feathery inclusions. These are arranged so as to give the crystals a striated appearance parallel to the direction of extinction, which is that of the vibrations with least velocity of transmission. The mineral appears to be either hydronepheline or natrolite.

The isotropic groundmass and its alteration-products, as well as the nepheline, contain large numbers of inclusions. Even the felspars, the brown hornblende, and the augite are not free from them. The majority are acicular, but rounded or irregular forms are very numerous in most of the spherical spaces. All are colourless [1] or cloudy, except those that are too small to show anything beyond a hairlike needle or a dot. The larger acicular crystals are rarely, if ever, found in the spheres, but minute needles are sometimes seen. The less well-defined inclusions occur in the colourless minerals throughout the rock.

Most, if not all, of the inclusions in the hornblende and augite appear to consist of apatite, which can also be recognized in the colourless groundmass—outside the spheres—by its hexagonal cross-section, high refractive index, and negative double-refraction. The crystals are, however, so small that their action on polarized light can only be detected (even when they are embedded in the isotropic matrix) in the case of a few of the larger individuals, which happen to lie with their axis parallel to the surface of the microscope-section. These needles of apatite have no definite orientation, and penetrate their hosts in all directions—irrespective of the structure of the latter. In some cases they seem to radiate from the hornblende.

There are other acicular inclusions which present many points of similarity to the apatite, but appear to have a rather lower refractive index, though higher than that of the colourless material in which they are embedded. The cross-section is often rhombic, yet in most cases it is too small for the shape to be determined. These inclusions rarely show signs of double-refraction; this may, however, be due to their small size. In most cases they follow definite directions, one or more systems of parallelism being generally visible. They sometimes swell out in an irregular manner, and may anastomose together. Occasionally a number of parallel needles are seen to project, like the teeth of a comb, from a main stem of similar material.

In the nepheline most of the inclusions lie parallel to the intersection of the base and prism, while others are parallel to the vertical axis.

[1] In some cases a slight trace of a greenish-brown tint is apparent; but this is due, I believe, to reflection from adjoining hornblendes. Similar acicular colourless inclusions are described as occurring in the Lake Champlain rocks [13] p. 36.

In the isotropic material filling the interstices between the coloured minerals, the arrangement of the inclusions is somewhat similar to that in the nepheline, though rather less regular in character; but groups of parallel inclusions at right angles one to the other may be distinguished. The inclusions in the colourless spherical spaces also usually show two systems of linear arrangement, at right angles one to the other. In one of the colourless spaces that appears to be isotropic, even in convergent light, numerous hairlike needles may be observed; the most conspicuous of these lie approximately in the plane of the section, and show an orientation in three directions meeting at angles of 60°. Others are inclined at a considerable angle to the section, and these also probably lie in symmetrical directions. In another case minute ill-defined inclusions are arranged in six directions, meeting each other at angles of 30°.

The rounded and irregular inclusions, though often occurring in straight lines, are also found in irregular curves, which are sometimes continuous with a rectilinear arrangement. It is doubtful whether any of the acicular inclusions except the apatites penetrate the coloured minerals. Where they seem to do so it is, I believe, an optical illusion due to superposition.

The true nature of the majority of these inclusions must be left undecided. Many are, as I have said, apatites; others are liquid-, or, in a few cases, gas-cavities; and some may be minute ægirines or hornblendes which are too small for determination.

Under a high power indications of an imperfect cleavage are clearly visible in the isotropic matrix, especially in the circular spaces (see Pl. II, fig. 2). Generally two cleavages are seen, perpendicular one to the other, though the inclination of the lines where they meet the microscope-section sometimes deviates from a right angle. The cleavage-cracks are usually parallel to the principal directions followed by the inclusions; they sometimes pass into curves at their extremities. In the interstices between the older minerals, faint traces of a similar rectangular cleavage are occasionally seen.

IV. Chemical Analyses.

The rock was crushed, and the powder separated by means of the double iodide of mercury and potassium. The material collected with an average specific gravity of a little over 2·2, was found to consist mainly of an isotropic substance; a few small prisms of ferromagnesian silicates were seen to be embedded in it, and no doubt a little nepheline and felspar were also present.

This separated material was treated with acid, and the dissolved bases were determined.

The following table summarizes the results of this analysis, and the inferences that may be drawn as to the composition of the isotropic groundmass. Other analyses of similar character are appended, as well as the percentage composition of typical nepheline

and analcime. The molecular proportions are in some cases also tabulated :—

	I *a*. per cent.	I *b*. per cent.	M.	II *a*. per cent.	II *b*. per cent.	M.	III. per cent.	IV. per cent.	M.	V. per cent.	VI. per cent.	M.	VII. per cent.	M.
SiO_2	52·79	53·02	3·94	53·43	54·21	4·04	52·38	51·24	2·17	54·51	54·67	4·00	43·93	2·25
Al_2O_3 ...	21·60	22·78	1·00	20·86	22·71	1·00	22·92	24·00	1·00	23·20	23·12	1·00	33·25	1·00
Fe_2O_3 ...	1·96	...	...	2·61	...	...	·75	1·20						
MgO......	undetd.	...	...	·29	...	...	·49	·33						
CaO	·66	...	...	1·14	...	...	2·26	1·68	...	·37				
Na_2O } ...	14·80	15·56	1·12	11·63	12·66	1·05	10·66	11·61	·73	14·30	14·05	1·00	15·15	1·00
K_2O }				2·51	2·73		2·13	1·25		·26			7·67	
H_2O	8·19	8·64	2·15	7·06	7·68	1·92	7·50	8·47	2·23	8·42	8·15	2·00		
Cl	...	...	...	...	...	...	...	...						
Totals......				99·53			99·59	99·78		101·06				

[Columns headed by the letter M represent the molecular proportions of the oxides in the column immediately to the left.]

No. I *a* is the analysis of the separated portion of the Girnar rock. The 'silica' includes a small amount of insoluble extraneous material. All the iron in this analysis was estimated as ferric oxide. The soda includes the potash, which was not separately determined on account of the small amount of material available. The water was calculated by difference, and the figures given include the small amount of manganese and magnesia that may have been present.

No. I *b* is the same analysis, but the chemical constituents of the hornblende have been deducted, on the assumption that it has the composition of barkevikite. For this purpose the mean of the analyses of specimens from Skudesundskyar and Brevig (2 & 3 in Dana's 'System of Mineralogy,' 6th ed., 1892) were taken.[1]

It was assumed as an approximate hypothesis that the iron present in No. I *a* was derived from the hornblende, and the corresponding amount of the other constituents of the hornblende were calculated on that basis. The silica and oxide of titanium were deducted from the silica of No. I *a*, the soda and potash from the soda, and the magnesia and manganese-oxide from the loss assumed to represent water. The whole were then recalculated as percentages of what remained.

No. II *a* is the analysis, given by Hunter & Rosenbusch, of the isotropic matrix of the monchiquite from Km. 36, Santa Cruz Railway, Rio de Janeiro.

No. II *b* is the same corrected, as described by Mr. Pirsson (see p. 39).[2]

No. III is the mean of two analyses of the analcime of the 'analcite-basalt' described by Mr. Lindgren from the Highwood Mountains of Montana [9]. See also [19] p. 684.

No. IV is the analcime from the 'analcite-basalt' described by Mr. Whitman Cross from Colorado (22). In the lime, ·06 of strontia

[1] Except in the case of silica and oxide of titanium, which are taken from the Brevig analysis, as that alone gives them both.

[2] The molecular ratios are slightly different from those tabulated by Mr. Pirsson, as more exact atomic weights are used.

is included, and ·62 of the water was given off over sulphuric acid.

No. V is the mean of eighteen analyses of analcime from the 6th ed. of Dana's 'System of Mineralogy' (1 to 19, but omitting 3).

Finally, Nos. VI & VII represent the theoretical composition of analcime and nepheline respectively.

The similarity of the figures for analcime to those of Nos. I *b*, II *b*, III, & IV is very striking.

The foregoing comparison of analyses is sufficient to show that the composition of the isotropic material in the Girnar rock approximates closely to that of analcime.

V. The Nature of the Isotropic Groundmass.

We can have little hesitation in coming to the conclusion that much, if not all the isotropic material in the rock which has been dealt with in the present paper consists simply of the mineral analcime. Like that substance, it is isotropic; has a low index of refraction; gelatinizes with acid; its specific gravity is about 2·2; and it has the same chemical composition. Yet it might have all these characters in common with analcime, and nevertheless be a structureless glass. But the arrangement and orientation of its inclusions, and the distinct traces of cleavage which are visible, show that it is crystalline in structure. Being crystalline, its isotropic character naturally places it in the cubic system; and with this determination the character of the symmetry indicated by the cleavage and the majority of the inclusions is in no way inconsistent.[1]

It is remarkable that in this occurrence of the mineral there should be rarely, if ever, any trace of a crystalline boundary; but this will be explained, if we remember that the analcime must have been the last mineral to form, and is therefore naturally allotriomorphic. It is more difficult to understand the complete absence of anomalous double-refraction, manifested by faint luminous bands under crossed nicols; but this exceptional behaviour cannot be considered a sufficient ground for refusing to accept the identification with analcime—a determination which is supported by the fact that a similar isotropic substance is found filling the interstices between the minerals of a rock at a distance of about 1½ miles, near the foot of the western slope of the central ridge of Girnar, a few yards south of the carriage-road. Here the grain of the rock is much coarser, and the presence of glass seems in the highest degree improbable. (I hope to give a detailed description of this rock at an early date.)

It is important to observe that the occurrence of an analcime-matrix implies the survival of a magma of the same composition after

[1] Some of the inclusions appear to be parallel to the edges of the cube, and there is reason to suppose that others are parallel to the edges of the eikositetrahedron (trapezoidal triakis-octahedron) in which analcime crystallizes.

the crystallization of the other constituents. The fact that a magma with practically identical chemical composition appears in so many instances to represent the portion of the rock that remained longest unsolidified, is a very significant fact. It can only be interpreted as indicating that analcime is an eutectic compound; that is, it represents a combination of silica, alumina, soda, and water, with a little potash, which solidifies at a lower temperature than any mixture of those substances which differs to any considerable extent in the proportions of its constituents, or in having an admixture of other materials: see [31]. If, however, when such a magma was all that remained to be solidified, the rock were cooled with sufficient rapidity, we should have a glass with the same composition as the analcime-magma. Rocks similar in all respects to that which I have described, but with a matrix that is glassy instead of crystalline, must therefore be expected to occur; and we should accept nothing short of actual traces of crystalline structure, as conclusive evidence that we are dealing with an isotropic mineral, and not a glass.

The question of the true nature of the type-rock from Brazil must therefore be still left in suspense, though the existence of fluidal structure in one locality tends to show that in places the rock is in fact a glass, while the clear subcircular spaces may in other instances raise some presumption in the contrary direction. But the specimens which, through the kindness of Mr. O. A. Derby, I have had an opportunity of examining, show no spherical areas approaching those of the Girnar rock in regularity of shape, and the isotropic material filling them is much less clear and transparent. I may add that the occurrence of the Brazilian rock in very narrow dykes '10 to 20 or 40 centimetres in diameter' in gneiss, which was probably at a comparatively low temperature at the time of the intrusion, would seem to favour the possibility of the matrix being glass.

I would deprecate any specialization of the use of the term monchiquite in respect of the physical character of the matrix, where its chemical composition is that of analcime, as the distinction between the glassy and the crystalline groundmass may imply only a slight difference in the circumstances of consolidation, and there is no reason why we should not have both glass and analcime in the isotropic material visible in the same microscope-section.

As indicated by Rosenbusch [10] p. 455, the chemical composition of this groundmass differs from that of a nepheline-syenite simply in the amount of water, and to some extent in the proportion of the alkalies. Rosenbusch lays stress on the association of monchiquites with nepheline-syenites [10] pp. 447, 455, [20] p. 538, & [24] p. 236, of which the present occurrence is yet another instance.

VI. The History of the Rock.

The question of the order of crystallization of the different minerals and the circumstances under which they were formed is not a simple one.

of the crystallization, in the manner already described, of the analcime which now occupies them. The only alternative to this explanation is to suppose that the spheres were originally formed by the crystallization of leucite, and that this mineral and the leucite or nepheline occupying the interspaces between the other minerals were subsequently altered into analcime.[1] It cannot be denied that this is possible, but there is no evidence that such a change has taken place; and the absence in the spherical spaces of the concentrically arranged inclusions so characteristic of leucite is a serious difficulty in the way of such an hypothesis.

VII. Bibliography.

I. Analcime and Monchiquites.

[1] Glocker, E. F. 'Ueber einige Erscheinungen an Kalkspathformen' Nov. Act. Acad. Cæs. vol. xxiii, pars ii, pp. 809–11 (1852).

[2] Tschermak. 'Ueber secundäre Mineralbildungen in dem Grünsteingebirge bei Neutitschein' Sitzungsber. kais. Akad. Wissensch. Wien, vol. xl, pp. 122–23 (1860).

[3] ——. 'Felsarten von ungewöhnlicher Zusammensetzung in den Umgebungen von Teschen & Neutitschein' Ibid. vol. liii, pp. 275–81 (1866).

[4] Bořický, E. 'Petrographische Studien an den Phonolithgesteinen Böhmens' Archiv der Naturwiss. Landesdurchforsch. Böhm. vol. iii, sect. ii, pp. 66–74 (1873).

[5] ——. 'Petrographische Studien an den Basaltgesteinen Böhmens' Ibid. vol. ii, sect. ii, pt. ii, pp. 172–82 (1874).

[6] Möhl, H. 'Mikromineralogische Mittheilungen' Neues Jahrb. pp. 696–98 (1875).

[7] Werveke, L. van. 'Ueber den Nephelin-Syenit der Serra de Monchique im südlichen Portugal & die denselben durchsetzenden Gesteine' Ibid. vol. ii, pp. 177–86 (1880).

[8] Rohrbach, Carl E. M. 'Ueber die Eruptivgesteine im Gebiete der schlesisch-mährischen Kreideformation' Tscherm. Min. Petr. Mitth. vol. vii, pp. 31–33 (1886).

[9] Lindgren, W. 'Eruptive Rocks from Montana' Proc. Calif. Acad. Sci. ser. 2, vol. iii, pp. 51–57 (1890).

[10] Hunter, M., & H. Rosenbusch. 'Ueber Monchiquit, ein camptonitisches Ganggestein aus der Gefolgschaft der Eläolithsyenite' Tscherm. Min. Petr. Mitth. vol. xi, p. 445 (1890).

[11] Williams, J. R. 'The Igneous Rocks of Arkansas' (with Additions by J. F. Kemp) Ann. Rep. Geol. Surv. Arkans. vol. ii, pp. 66, 78–80, 107–16, 290–95, 352–54, 393–402 (1890).

[12] Rosenbusch, H. 'Mikroskopische Physiographie der petrographisch-wichtigen Mineralien' 3rd ed. pp. 331–34 (1892).

[13] Kemp, J. F., & V. F. Marsters. 'The Trap-Dykes of the Lake Champlain Region' U.S. Geol. Surv. Bull. No. 107, pp. 32–39 (1893).

[14] Zirkel, F. 'Lehrbuch der Petrographie' 2nd ed. vol. ii, p. 680 (1894).

[15] Hibsch, J. E. 'Beiträge zur Geologie des böhmischen Mittelgebirges' Tscherm. Min. Petr. Mitth. vol. xiv, pp. 99–100 (1895).

[16] Fairbanks, H. W. 'On Analcite-Diabase from San Luis Obispo County, California' Bull. Dep. Geol. Univ. Calif. vol. i, pp. 273–300 & pls. xv–xvi (1895).

[17] ——. 'The Geology of Point Sal' Ibid. vol. ii, pp. 19–38 & pl. ii (1896).

[18] Weed, W. H., & L. V. Pirsson. 'Geology of the Castle Mountain Mining District (Montana)' U.S. Geol. Surv. Bull. No. 139, pp. 114–17 & 136 (1896).

[19] Pirsson, L. V. 'On the Monchiquites or Analcite-Group of Igneous Rocks' Journ. Geol. Chic. vol. iv, p. 679 (1896).

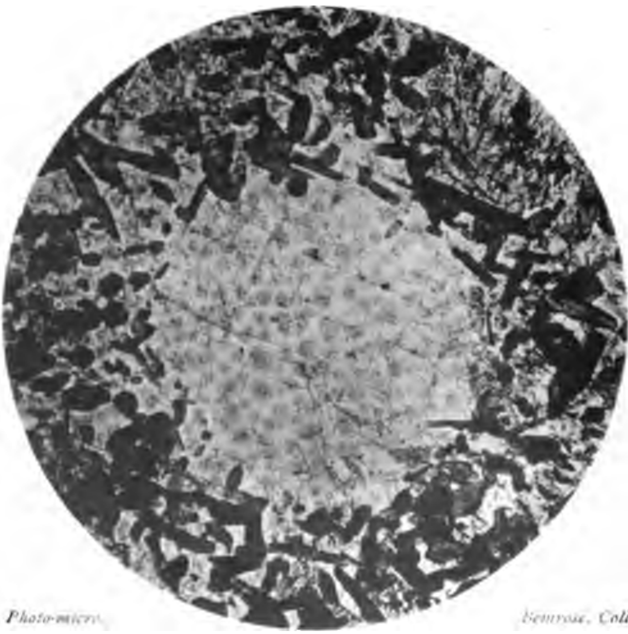
[1] This is supposed to have been the case with the 'leucite-monchiquites' of Bohemia, where there are now similar spaces filled with analcime [16] p. 100, [20] p. 545, & [24] p. 234. I can see no evidence of such a change in a microscope-section of a specimen from Babutin, which I owe to the kindness of Prof. Judd. The rock has, however, suffered considerable alteration, which is not the case with the Girnar monchiquite.

1.

X 18.

2.

X 41.



F. Chapman, Photo-micro. Bemrose, Collo., Derby.

Monchiquite from Mt. Girnar.

[20] ROSENBUSCH, H. 'Mikroskopische Physiographie der Massigen Gesteine' 3rd ed. pp. 377–80 & 537–46 (1896).
[21] PRIOR, G. T. 'Note on the Occurrence of Rocks allied to Monchiquite in the Island of Fernando Noronha' Min. Mag. (Journ. Min. Soc.) vol. xi (1897) p. 171.
[22] CROSS, WHITMAN. 'An Analcite-Basalt from Colorado' Journ. Geol. Chic. vol. v, pp. 684–93 (1897).
[23] WASHINGTON, H. S. 'Sölvsbergite & Tinguaite from Essex County (Mass.)' Am. Journ. Sci. ser. 4, vol. vi, pp. 182–87 (1898).
[24] ROSENBUSCH, H. 'Elemente der Gesteinslehre' pp. 233–37 (1898).
[25] BRÖGGER, W. C. 'Die Eruptivgesteine des Kristianiagebietes III: Das Ganggefolge des Laurdalits' pp. 62–63 (1898). [In Videnskabsselsk. Skrift. I. mathemat. naturv. Kl. 1897, No. 6.]
[26] LOEWINSON-LESSING, F. 'Studien über die Eruptivgesteine' Congrès Géol. Internat. Compte-rendu VIIème Sess. (1897) pp. 289–94 (pubd. 1899).
[27] FLETT, J. S. 'The Trap-Dykes of the Orkneys' Trans. Roy. Soc. Edinb. vol. xxxix, pp. 887–901 (1900).
See also [31] p. 191.

II. Leucite and Pseudoleucite.

[28] HUSSAK, E. 'Ueber Leucit-Pseudokrystalle im Phonolith (Tinguait) der Serra de Tingua, Estado Rio de Janeiro (Brazil)' Neues Jahrb. vol. i, p. 166 (1890).
[29] PIRSSON, L. V. 'On some Phonolitic Rocks from Montana' Am. Journ. Sci. ser. 3, vol. l, pp. 395–96 (1895).
[30] WEED, W. H., & L. V. PIRSSON. 'Missourite, a New Leucite-Rock from the Highwood Mountains of Montana' *Ibid.* ser. 4, vol. ii, p. 315 (1896).
See also [11] pp. 267–74, 280–81 & 284–85.

III. Miscellaneous.

[31] TEALL, J. J. H. 'British Petrography' pp. 394–97 (1888).
[32] ——. 'On the Amygdaloids of the Tynemouth Dyke' Geol. Mag. p. 481 (1889).

EXPLANATION OF PLATE II.

Fig. 1. Microscope-section of monchiquite from Mount Girnar, Junagarh (Kathiawar) × 18, showing brown hornblende, green augite, and colourless circular areas with interstitial material.

2. The same × 41, showing a single circular area containing analcime with rectangular cleavage. A portion of a large crystal of augite is seen in the upper right-hand quadrant.

DISCUSSION.

Mr. PRIOR said that, although many may deplore the continued increase of rock-names, yet the use of a new name in the case of the monchiquites appeared to be perfectly justified, since they have such well-marked characteristics, both mineralogical and geological. In Brazil and Canada these rocks are of great age, but in Bohemia they occur in association with Tertiary volcanic rocks. He would be glad if the Author could give some idea as to the age of the Indian rock. He thought that the analytical evidence was not sufficient to support the idea that analcite formed under pressure could contain more potash than ordinary analcite.

Gen. MCMAHON thought that in attempting to decide the question whether the analcime in the monchiquite described by the Author was an original or a secondary mineral, we should give great weight to the probabilities of the case. It seemed to him highly improbable that a hydrous zeolite which contained no less than 8·2 per cent. of water was the product of igneous or aqueo-igneous fusion at the high temperature of molten rock. He thought the probability was that

the analcime was formed by aqueous agents after the consolidation of the monchiquite. This probability was strengthened by the fact that analcime had been formed artificially in the laboratory from both nepheline and leucite. Stewing in a solution of soda appeared to be all that was necessary to convert leucite into analcime. He had sometimes been asked why leucite was found in such restricted areas: he thought that one cause for this was that leucite was readily converted into analcime and other secondary minerals; and consequently, in rocks of considerable geological age, the leucite that they may originally have contained had long since been converted into secondary minerals. The rounded discs filled with analcime, shown in the slides exhibited on the screen, were very suggestive of pseudomorphs after leucite. The presumption in favour of the analcime in the rock described by the Author being a secondary mineral seemed so great that an igneous origin ought not, in the speaker's opinion, to be assigned to it, unless the verdict was supported by very cogent evidence.

Prof. Judd pointed out that in his paper the Author had not only given a very clear statement of the whole problem of the presence of analcime as an original constituent in igneous rocks, but had added two fresh facts in support of the contention that such associations actually exist. His recognition of the cleavage and crystalline form of the substance appeared to be new, and constituted certainly very valuable results.

Mr. Harker said that this paper afforded additional evidence that the interstitial isotropic substance of the monchiquites is not glass but analcime, and is an original igneous product. The primary or secondary origin of the analcime-spheroids is perhaps a more doubtful question, and there seems to be room for suspicion that these may be pseudomorphs after leucite—a suspicion strengthened by their richness in potash. Whatever the interpretation, this Indian occurrence presents numerous points of interest.

The President and Prof. Watts also spoke.

The Author stated, in reply to Mr. Prior, that it was uncertain whether these rocks were an inlier in the Deccan Trap or represented a deep-seated portion of the same igneous series. In the latter case they would be of late Secondary or early Tertiary age. In answer to Gen. McMahon, he referred to the fact that some, perhaps most, igneous magmas contained a considerable amount of water, as was shown by its occurrence in glasses which, like many pitchstones, had consolidated under pressure. There was no reason, therefore, why minerals containing the elements of water should not crystallize from fusion if the pressure were sufficient to prevent the separation of the water from the magma in the form of steam: biotite was an example of such a mineral. With regard to Mr. Harker's doubts as to the formation of anhydrous substances such as nepheline and orthoclase from a hydrous mineral like analcime, the Author suggested that it was analogous to their crystallization from an igneous magma containing water. In the latter case the nepheline and felspar were formed directly from the magma, in the former analcime represented an intermediate stage.

5. On certain Altered Rocks from near Bastogne,[1] and their Relations to others in the District.

By Catherine A. Raisin, D.Sc. (Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S. Read November 7th, 1900.)

Contents.

I. Introduction.

Much has been written about the exceptional rocks of the Ardennes, but the petrographical work has been treated, in some memoirs, apart from the field-evidence. This, indeed, owing to the limited occurrence of the most peculiar specimens, is not easy to obtain. It seemed then that a detailed study of a few interesting examples of the rocks, and of their relations in the field, might be worth a brief record. Further, eminent authorities have expressed different opinions as to the cause of the alterations. André Dumont in his famous monograph[2] described numerous observations, and inclined to the view that the structures were the result of contact-action. Prof. Barrois,[3] from comparison of specimens with those of Britanny, supported this theory. A. von Lasaulx[4] added the important evidence that a granite occurs in the Hohe Venn. Other authorities, however, have described the folding, contortion, and faulting of the rocks, and attribute the changes to mechanical influences. This opinion is advocated by Prof. Renard in a valuable petrographical paper,[5] and by Prof. Gosselet in his exhaustive memoir on the district.[6] Thus I became interested in the question, and, at the desire of Prof. Bonney (as he was unable at that time to undertake the

[1] [Bastogne is a small town in the extreme north-east of the Belgian Ardennes, a few miles away from the frontier of the Grand Duchy of Luxemburg.]

[2] 'Mémoire sur les Terrains Ardennais & Rhénan' p. 232. [See also Mém. Acad. Roy. Belg. vol. xx, 1847.]

[3] Ann. Soc. Géol. Nord vol. x (1883) p. 205. The comparison here is drawn, however, with the porphyroids.

[4] 'Der Granit unter dem Cambrium des Hohen Venn' Verhandl. Naturh. Ver. Preuss. Rheinl. vol. xli (1884) p. 418. See also E. Dupont, Bull. Acad. Roy. Belg. ser. 3, vol. ix (1885) pp. 110–114.

[5] A. Renard, 'Les Roches Grenatifères & Amphiboliques de la Région de Bastogne' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 33–39.

[6] 'L'Ardenne' (1888) p. 762. See also Eugen Geinitz, 'Der Phyllit von Rimognes in den Ardennen' Tscherm. Min. & Petr. Mittheil. vol. iii (1881) pp. 533–40.

investigation) I visited the district in 1898, and collected many specimens. After careful study of these, I made a second expedition in the summer of 1899, and gained observations over a wider area of country.

In the course of this investigation I have received much valuable help from Prof. Bonney, who has examined all the specimens, and has made many important suggestions. I have had also the advantage of the loan from his collection of many slides of rocks, from this and other localities, for comparison.

The rocks of the district are classed as Cambrian and Devonian. The former, according to the map, occupies four patches:—two larger, Stavelot and the Meuse; two smaller, Serpont and Rocroy. The Cambrian rocks are generally blackish, and include shaly micaceous grits, shales, slates, and strong compact rocks, often quartz-veined, which in the hand-specimen resemble quartzites, but under the microscope have the appearance of a quartz-grit. The different species sometimes graduate one into the other, as along the road at Trois Ponts, where they alternate repeatedly, while they form a much-folded series by the railway-station below. Under the microscope, we see scattered mica, partly or wholly secondary, within the gritty groundmass, and often squeezed dark carbonaceous streaks.

The Lower Devonian slates and grits extend over wide areas of the country, exhibiting at places alterations which I shall describe later. Lithologically they bear much resemblance to the Cambrian with similar micromineralogical change, a resemblance which is found also in Britanny in the 'grès feldspathiques,' the 'grès armoricains,' and in the later (Devonian) rocks.

II. Mineral Modifications.

(1) Results of Pressure.

The district of the Ardennes is familiar to all geologists as an example, both in Cambrian and Devonian, of the results of pressure, which has caused a very general slaty cleavage, while foldings and overthrust-faults have been described and figured from many places.

A much-crushed quartz-felspar rock occurs at several localities, as at Lamersdorf, south of the village, where it is described by A. von Lasaulx.[1] In these quarries the base of the series consists of a dusty pale-banded argillite followed by a layer, containing large fragments of quartz, which is almost certainly a grit, although the quartz has some resemblance to a broken-up vein. Bosses of the quartz-felspar rock succeed, and it is found in a road-cutting on the hillside below. All these rocks exhibit an imperfect cleavage dipping roughly south-eastward. On examination with the microscope, we see in all of them fragments of quartz dispersed in a groundmass

[1] Verhandl. Naturhist. Ver. Preuss. Rheinl. vol. xli (1884) pp. 445–48.

of minute filmy mica and elongated grains of secondary felspar. It is difficult to decide with certainty the nature of the overlying quartz-felspar rock; on the whole, it seems more probably a crushed grit than a porphyroid, although some of the quartz has the aspect of corrosion by a magma such as is often seen in a quartz-felsite. The rock differs, however, from the porphyroids of the district in not containing the large, much-corroded felspar-crystals.

The rocks bear a strong resemblance to those from the Llanberis section, North Wales, which include porphyroids and crushed felspathic grits. Near Salm Château certain crushed rocks occur, which probably have an origin similar to those of Lamersdorf.

In other cleaved rocks some of the minerals are certainly secondary, including microlithic white mica, and possibly the better-defined crystals of ilmenite, ottrelite, etc. The micromineralogical development is doubtless the result of pressure. For instance, in a gritty phyllite (from St. Pierre) consisting of angular fragments of quartz (with one or two of white mica, biotite, tourmaline, and possibly a zircon), minute crowded mica-films are developed mainly along the cleavage-planes. Of the better-defined secondary minerals, ilmenite-crystals, usually small, occur,[1] frequently along cleavage or strain-slip planes, as if their development also might be connected with pressure. The origin of the well-known ottrelite offers some difficulty. It may be partly a result of contact-action, but some indirect evidence rather connects it with pressure-results. It occurs generally in crushed rocks—for instance, one schistose greyish grit from near Viel Salm, crossed by shining micaceous crush-planes, contains ottrelite-crystals (about 1·5 mm. broad) with rich brown cleavage-faces. The crystals (in this and other rocks) when seen under the microscope have the parallel sides and irregular ends shown by Prof. Renard,[2] as if they had grown through the crushed material, like the biotite and hornblende described by Prof. Bonney.[3] The last-named author has noticed a mineral resembling one of the chloritoid group in a Nufenen rock, where there is neither proof nor any probability of contact-action.[4] In many slices of the Ardennes rocks patches of ferrite are associated with the ottrelite, as if the isolated crystals may have originated from scattered grains of iron-oxide, which borrowed constituents from the surrounding mass.

[1] See A. Renard, 'Recherches sur la Composition & la Structure des Phyllades Ardennais' pt. ii, Bull. Mus. Roy. Hist. Nat. Belg. vol. ii (1883) p. 127.

[2] 'Note sur l'Ottrélite,' A. Renard & Ch. de la Vallée Poussin, Ann. Soc. Géol. Belg. vol. vi (1879) p. 61 & pl. ii, figs. 1–2. Compare the similar form of chloritoid described by Barrois, 'Note sur le Chloritoïde du Morbihan' Bull. Soc. Minéral. France, vol. vii (1884) p. 39.

[3] 'On a Secondary Development of Biotite & of Hornblende in Crystalline Schists from the Binnenthal' Quart. Journ. Geol. Soc. vol. xlix (1893) p. 104.

[4] 'On the Crystalline Schists & their Relation to the Mesozoic Rocks in the Lepontine Alps' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 234.

(2) Probable Contact-Alterations.[1]

It would be interesting if we could trace exactly the distribution of the more and the less modified types among the altered rocks of the Ardennes; but quarries are far apart, and the country between is generally a rolling plateau, sometimes thickly wooded. The modifications, however, are found chiefly over the 'zone of Paliseul,' as Dumont termed the country extending from west of the Meuse to east of Bastogne.[2] In this tract the chief alterations occur around certain centres (as, for example, Libramont, Bastogne) over areas of a few miles. Thus the distribution of these rocks is such as might be expected, if an important igneous mass occurred below the surface.

Further, we can trace progressive alteration in specimens collected in certain districts, and sometimes even in those from a single quarry. For instance, some rocks with faint spots (as from near St. Pierre) show under the microscope a matted, minutely crystalline mass of quartz or secondary felspar and white mica with some biotite. In a more gritty band (from near Mont St. Etienne west of Bastogne) the quartz and felspar-grains are coarser, surrounded by minute greenish films with some graphite, and the flakes of biotite are larger and clustered. Other types have more numerous or more scattered films; or more abundant biotite, in nests and groups. In others, streaks of biotite and associated minerals (some sphene, iron-oxide, etc.) give the grit a banded appearance. In all these, the micromineralogical change is not greater than is often found in pressure-modified rocks; but the microliths are not connected with pressure-planes, and the development of biotite (especially in clusters) is suggestive of contact-alteration. It has the indented or interrupted form of, and a general similarity in colour and appearance to, the mica in undoubted contact-rocks.[3]

The change in the rocks described above is slight and chiefly traceable under the microscope, but previous observers have obtained stronger evidence. Thus Von Lasaulx found a granite in the Hohe Venn beneath upheaved Cambrian strata.[4] Although the granite is not exposed in other localities, yet at many places veins occur of quartz, sometimes with felspar and mica, such as would often be connected with a granite-mass. Further, M. Dupont obtained from near Libramont crystals which he identified as doubtless chiastolite, and this would be considered, as he points out, certain evidence

[1] Excluding the garnetiferous and hornblendic rocks.

[2] The ottrelite-rocks of Salm, and the granite of Lamersdorf in the Hohe Venn, are from other and distant localities.

[3] Such as those from Glendalough (Ireland), slices from which were kindly lent me by Prof. Bonney; or those from Andlau in the Vosges.

[4] The railway-cutting where this was exposed is grassed over, and I could not examine the adjoining schists described by Prof. Gosselet. Close by, near the bend of the road, is quarried a pale brownish muddy rock containing grains of quartz, possibly fragmental, but the mass is quite decomposed.

of 'the proximity of a granite.'[1] I examined from this place many specimens, among which I could trace under the microscope stages of increased alteration. In two adjacent quarries, I found veins of quartz, felspar, and mica. If these are not connected with a granite but are only mineral veins, their occurrence among the fine-grained mudstones is at least singular.

Specimens of the sedimentary rocks (taken at various distances from the veins) are sometimes slightly spotted, but do not otherwise suggest contact-alteration, although such effects may be masked by the dusty decomposed condition of the material. The microscopic constituents, however, are mostly recrystallized. Among the specimens from one quarry, I find:—Firstly: at about 16 feet from the vein, a brown-stained argillite, slightly indurated in one band. The groundmass, crowded with narrow plates of iron-oxide, is composed mainly of matted micaceous flakes of uniformly small size (average often ·03 mm. in length), generally with an orientation. Occasionally a prism of hornblende or tourmaline occurs. Secondly: at about 2 feet from the vein occurs an iron-stained mudstone with minute dark spots. A thin slice shows rather large quartz-grains irregular and agglutinated, large mica without orientation (often about ·05 mm. long), and, in a finer-grained band, minute garnets. Thirdly: at about 1 foot from the vein comes a dark, strong, ferruginous grit, of clear quartz, pale green chlorite (probably altered biotite) in larger flakes, generally grouped (often ·2 mm. in length), and numerous minute garnets. The latter are partly rounded, and much cracked within. Some iron-oxide and an occasional grain of (?) staurolite occur. Thus the abundant development of minute garnets and the coarser-grained crystallization are found nearer to the vein.

In a neighbouring quarry I observed, on my first visit, branching veins resembling rotten granite, which, however, in 1899 were no longer visible. Specimens taken from this pit are much weathered; but on examining thin slices under the microscope, it is seen that the flakes transitional from biotite to chlorite (brown or greenish to almost colourless) are very large and frequently in clusters. One specimen (to which a fragment of a vein adheres) contains flakes often ·15 mm. long, embedded in a clear quartz-felspar mosaic including some grains of (?) corundum. With this, we may compare two other specimens from a third quarry close at hand. One consists of clear grains parted by thin micaceous strings, and contains some iron-oxide and a few minute garnets. A second specimen, traversed by three subparallel veins (about $\frac{1}{3}$ inch broad), consists mainly of minute mica-flakes at right angles to the veins, and contains abundant minute garnets. All these facts at any rate show increasing alteration such as granite produces, as one approaches the veins.

[1] E. Dupont, 'Sur l'Existence de Roches Maclifères dans le Terrain Dévonien Inférieur de l'Ardenne Belge' Bull. Acad. Roy. Belg. ser. 3, vol. ix (1885) pp. 110–14. Andalusite was described also from veins in the Cambrian rocks of Stavelot, from strata near Laifour (Cambrian), and from ejectamenta in the agglomerates of the Eifel.

(3) The Garnetiferous and Hornblendic Rocks.

Previous observers have called attention to the very limited distribution of these rocks in the field. Dumont noticed many examples,[1] which, as later authorities state, cannot now be seen. Prof. Gosselet quotes Dumont, and figures some drawings showing their mode of occurrence.[2] They are sometimes in rather short, generally lenticular bands, sometimes in 'nodules.'[3] Thus they are quickly worked out in the quarries, and loose fragments of them are few and scattered, preserved doubtless only by their superior hardness.

The petrographical characters of hand-specimens have been exhaustively described by Prof. Renard. The minerals, which he enumerates[4] as seen under the microscope, in the garnetiferous and hornblendic rocks and the 'phyllades,' are :—

(1) Graphite as fine dust, or as hexagonal scales; (2) iron-oxide often plate-like (hæmatite or ilmenite); occasionally magnetite is present; (3) titanite; (4) zircon; (5) apatite; (6) quartz; (7) white mica.

In the 'phyllades': (8) rutile, (9) tourmaline, (10) ottrelite (with sillimanite, pyrite, pyrrhotine), (11) and biotite, similar to that which I have described in the previous section, p. 59.

(12) Garnet often in sharp well-developed dodecahedra, with regularly arranged enclosures. I have also found garnet interrupted by much of the groundmass in a manner somewhat resembling micropegmatite.

(13) Hornblende in sheaves or tufts.

To these I would add the following minerals, some of which I have identified with hesitation in the absence of certain distinctive characteristics; and where the minerals are mentioned by name in succeeding pages, this must be taken only as the most probable identification :—

(14) Felspar (described by Prof. Gosselet).

(15) A mineral which forms crystals with straight sides, ragged ends, and a parallel cleavage, resembling mica or more closely an ottrelite: the crystals sometimes develop incurving tufts like the hornblende. The mineral always includes grains of the groundmass, which are sometimes so abundant that the crystals are scarcely more than suggested. Except for an occasional yellowish tint, probably iron-staining, it is practically colourless, but, on close examination with a high power, shows a very slight green. It is not at all, or very faintly pleochroic; and with crossed nicols its polarization-tints are so low as often to be barely perceptible—then dull greenish or yellowish-green. It has polysynthetic twinning like plagioclase, the above-named colours being striped with dull grey, green, or leaden blue. The mineral has at least one very well-marked cleavage, sometimes mica-like but more usually separating lath-shaped films; besides cross-cleavages which make with this an angle difficult to determine, because of the curvature. The twinning-stripes are occasionally transverse to the perfect cleavage. The mineral includes granular opacite, sometimes scattered irregularly, but generally aggregated along the cleavage-

---

[1] 'Mémoire sur les Terrains Ardennais & Rhénan' p. 305.

[2] 'L'Ardenne' (1888) pp. 787–91.

[3] *Ibid.* p. 785. Prof. Gosselet says that the 'metamorphic rock' occurs generally as 'nodules.' Prof. Renard says that it occurs .... 'en lits' .... 'en bancs minces' .... 'sous la forme d'amas couchés' .... 'sous la forme de nodules:' see Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 7.

[4] 'Les Roches Grenatifères & Amphiboliques de la Région de Bastogne' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 1–47; 'Recherches sur la Composition & la Structure des Phyllades Ardennais' *Ibid.* p. 215 & vol. ii (1883) p. 127.

planes and often between the laths.[1] The characteristics on the whole agree best with ottrelite, by which name it is hereafter designated.[2] The hornblende in the slides is usually green, shows distinct pleochroism from green to pale straw, and gives bright colours with crossed nicols; it is sometimes intercrystallized with the mineral described above as 'ottrelite.'

(16) Grains which show with crossed nicols the rich colours or bluish tints usual in epidote.

(17) Small grains, colourless, with high refraction, showing with crossed nicols a drab colour or pale pink and green. They have no marked cleavage, but sometimes a parallel twinning, are usually irregular in outline, with a tendency to a wedge-shape or scalenohedron, are undoubtedly secondary, and have even formed an irregular border along certain faces on one or two garnets. I have failed to identify this mineral.[3]

The next two minerals occur in a few cases in rock adjacent to the nodules:—

(18) Grains, colourless, not highly refractive, with bright polarization-colours, having one marked cleavage, and extinguishing straight; these may be scapolite.

(19) Grains (some rounded), colourless, crossed by two cleavages, highly refractive, showing often low interference-colours, extinguishing parallel to the long axis of the grain. I incline to identify this mineral as probably corundum, occurring often in what resemble fragmental grains.

The examples of garnetiferous and hornblendic rock to be described are from near Bastogne. North or north-east of that town, a rounded ridge formed of a flattened anticlinal has been cut, by both the road to Longwilly and the railway to Kautenbach, and quarried extensively for ballast along the railway to Gouvy. The quarries at the last-named locality have been probably cut back since Prof. Gosselet made a drawing of one nodular mass,[4] but I found in them two examples of the garnetiferous or hornblendic rock; and by the road to Longwilly, three.

I will begin by describing one of the last-named instances. This occurs in a craglet about 5 or 6 feet high, which consists of compact sedimentary rock with almost horizontal greyish bands and blackish

[1] I presume this mineral to be that figured by Prof. Renard in the 'Taunusian garnetiferous rocks' Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pl. i, fig. 2, and included by him in the variety of amphibole. In his earlier paper, Ann. Soc. Géol. Belg. vol. vi (1879) pp. 55, 65–67, he gives a full description of it and reasons for referring it to ottrelite rather than hornblende; but in 1882 (Bull. Mus. Roy. Hist. Nat. Belg. vol. i, pp. 19–22) he withdraws the previous identification, and accepts Dumont's reference to actinolite, remarking, however, that the large amount of alumina present in it is a difficulty.

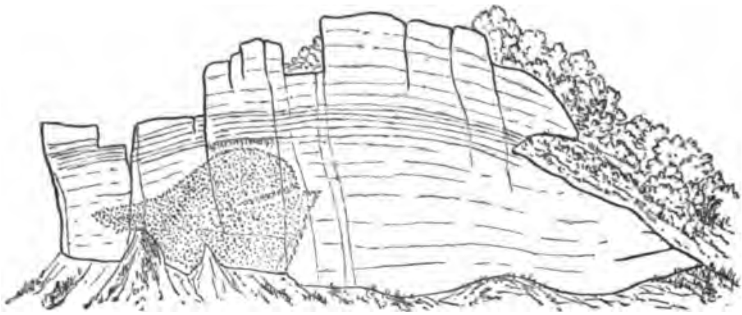
[2] The mineral agrees with the ottrelite of Dana, and differs from chloritoid in being feebly or not at all pleochroic. But the distinction of closely allied species is not clear:—Prof. Iddings places chloritoid under the ottrelite-group; M. Michel-Lévy and Dana (in an earlier text-book) place ottrelite under the chloritoid-group; Dana (in his 'System of Mineralogy,' 6th ed. 1892, following Tschermak) describes chloritoid and ottrelite as two species of the clintonite-group, but, speaking of the chloritoid in schists or phyllites, occurring in fan-shaped or sheaf-like forms, says that 'most of what has been called ottrelite probably belongs here' (*op. cit.* p. 642); Mr. G. Barrow, 'On the Occurrence of Chloritoid in Kincardineshire' Quart. Journ. Geol. Soc. vol. liv (1898) p. 154, suggests 'that chloritoid, ottrelite, etc. . . . . have really the same composition, if we could only obtain pure material to work upon.'

[3] It has been suggested to me that this might be sphene. We had considered the possibility, but were not very satisfied with that identification.

[4] 'L'Ardenne' (1888) p. 769 & fig. 208.

streaks. A patch seen on one joint-face is doubtless the section of a nodular mass; it measures about 56×36 inches, is nearly circular above, but projecting at the side as shown in the diagram, and shaped rather like a sprouting bulb lying on its side (fig. 1). The layers of the sedimentary rock directly above are slightly arched, and divided by small joints into lath-like structures. The 'nodule' and the surrounding mass are cut by vertical joints; and other joints mostly occupied by quartz-veins, tailing off below, occur between this 'nodule' and the next. The rock is spotted along certain lines, and seems indurated, weathering into ridges and furrows near to the nodule. This has an outer zone, about 1 to 2 inches thick, pale grey, crowded with sheaves and tufts of green hornblende without orientation. The next zone, brown, speckled, crowded with

Fig. 1.—*Craglet about 6 feet high, showing a nodular patch which measures 3 × nearly 5 feet: north-east of Bastogne, by the road to Longwilly.*



[The margin of the nodule, about 1 to 2 inches broad, is grey, the interior being black from abundant carbon. The nodule throughout is rich in hornblende-tufts, which, however, are seen more clearly in the greyer outer zone, and are specially well developed in two small included bands.]

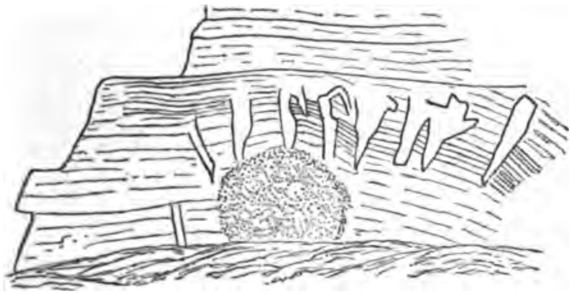
hornblende, has a fairly sharp boundary which can be traced across the stratification. The central area is dark, even blackish, and is dusty and crumbles easily. Further, a harder band (about $\frac{3}{4}$ inch thick) projects into the 'nodule' from one side; it is black, and crowded with crystals of hornblende; another enclosed band somewhat lenticular, about $\frac{1}{4}$ inch thick, is of a pale greyish colour.

On examining the sedimentary rock under the microscope, it is found to vary from a compact quartz-grit to an imperfect slate, sometimes crowded with filmy microliths. Grains of corundum (?) occur, possibly tourmaline; and biotite (sometimes bleached) is found not infrequently either in patches, or in flakes which may represent original fragments with subsequent enlargement. The secondary modifications, although all somewhat slight, do not always increase nearer to the nodule. The differences may be partly due to the original nature of the layers; but the hand-specimens are all fine-

grained, grey, rather dusty, faintly laminated, with no evident distinctions.

The rock directly adjoining the nodule, when examined under the microscope, is seen to consist mainly of clear quartz, and altered or secondary felspar, with abundant greenish microliths; biotite, chlorite, (?) epidote, and some zircons occur, all small. The external zone of the nodule has a clearer groundmass without the microliths or small flakes, though with small (?) epidote, but secondary minerals of more conspicuous size now appear. Sheaves and tufts are formed mainly of a green actinolite,[1] while certain highly refractive colourless granules often aggregated are probably epidote. The next browner zone seems to owe its colour to hæmatite, which forms either minute patches (sometimes within the hornblende) or a surface-deposit on grains of the groundmass. The colour of the centre is caused by the preponderance of black dust, probably carbon, which sometimes saturates the felspar as if formed from a carbonaceous mud. Thus successive zones are characterized by:—(i) clearer crystalline grains of the groundmass with microliths; (ii) still clearer groundmass; crystals of hornblende, some granular epidote; (iii) in addition, deposit of iron-oxide (hæmatite, etc.); (iv) in addition, deposit of carbon.

Fig. 2.—*Banded rock including a garnetiferous nodule; north-east of Bastogne, by the road to Longwilly.*



[The nodule measures about 2 feet across; is black, with a greyish margin; and contains small reddish garnets and small 'ottrelite.' The laminæ above the nodule are interrupted and slightly disturbed, along cracks filled by quartz-veins, narrowing downward.]

The projecting band previously mentioned is more compact and less carbonaceous, and contains actinolite-tufts, some of which grow into it from the adjacent rock. In the thinner ¼-inch band, the tufts are even clearer, projecting inwards or curving along the surface. They apparently grow more readily through fine-grained material,[2]

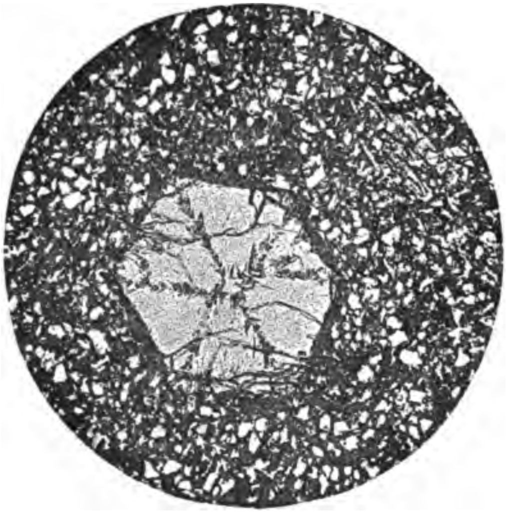
[1] See Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pl. i, fig. 2, pl. ii, fig. 1, & pl. iii, fig. 1.

[2] T. G. Bonney, 'The Garnet-Actinolite Schists on the Southern Side of the St. Gothard Pass' Quart. Journ. Geol. Soc. vol. liv (1898) p. 371. See also Proc. Roy. Soc. vol. lxiii (1898) p. 220.

which forms a streak in the band and contains blackish plates of ilmenite or hæmatite, with rather abundant small epidote (?).

A few yards away, where the cliff nearly reaches the road, is a second nodular mass of rounded outline about 2 feet across (fig. 2, p. 63). The rock here is grey, banded, finely laminated, sometimes showing current-bedding. The laminæ can be traced up to the sides of the nodule, and even into it (seen in thin slices), while above it they are slightly faulted and displaced, with a number of quartz-veins, all more or less wedge-shaped and pointing downward. At a lower level, and a few feet in front, are a banded indurated grit and a little slate. The margin of the nodule is blackish, weathering to slate-colour; it is crowded with crystals, steel-like when fresh, brown when weathered, and contains scattered reddish garnets, about 1 mm. in diameter. The mass of the nodule is similar, jointed

Fig. 3.—*Part of a slice for the microscope (× 40) taken from the nodule (by the road to Longwilly) shown in fig. 2, p. 63.*



[A garnet and a small imperfect crystal of 'ottrelite' are seen embedded in a carbonaceous groundmass. The garnet is mostly sharp-edged, with regularly arranged inclusions along crystallographic planes.]

somewhat rhomboidally, is firmer towards the exterior, but in the centre becomes dusty, crumbles away from around the small garnets,[1] and blackens the fingers when rubbed.

The marginal zone is seen under the microscope to consist of a mosaic with carbon-dust, and with curving sheaves of the supposed ottrelite. These, although apparently continuous, are really crowded with enclosed grains of the groundmass. In the next zone garnets appear, generally with a border of opacite (fig. 3).

[1] See A. Renard, Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 9.

They are sometimes imperfect, and crystallized against a patch of ottrelite.

The interior of the nodule consists of the same minerals with some small sharp-edged crystals, probably white mica, some of mineral No. 17 (see p. 61), small epidote, and patches of hæmatite or limonite sometimes embedded in the ottrelite. In a squeezed part, the sheaves of ottrelite grow across the planes of schistosity.

This garnetiferous nodule appears isolated; but about 2 feet away, an irregular step left in quarrying shows altered rock, which may have been previously a prolongation of the 'nodule.' The mass is a compact greyish grit (with silvery mica along pressure-planes) forming indurated, dark, somewhat speckled bands above and below; while the central portion (about 1 foot thick) is more altered, crowded with the supposed ottrelite, and similar to the rock last described.

Thin slices of the upper and lower bands are crowded with minute greenish films and carbonaceous dust, and contain ilmenite or hæmatite, with occasionally a minute flake of biotite. This opacite is especially abundant along certain blacker layers. The altered central band contains much carbon, crystals of iron-oxide, sheaves of ottrelite, and small crystals of white mica which terminate irregularly and fit on to adjacent grains, and thus evidently are of secondary origin; garnets, however, are absent.

The cutting along the road extends for 100 yards or more, and exhibits grits, often banded and very fine-grained, containing sometimes (in various specimens) filmy chloritic patches, iron-oxide, white mica, possible scapolite, and a little biotite. The groundmass occasionally forms a clear recrystallized mosaic containing rounded grains of corundum (?), and sometimes lath-shaped crystals of mineral No. 17 or possibly a carbonate, which in one slice have grown across the cleavage of included wedges of slate.

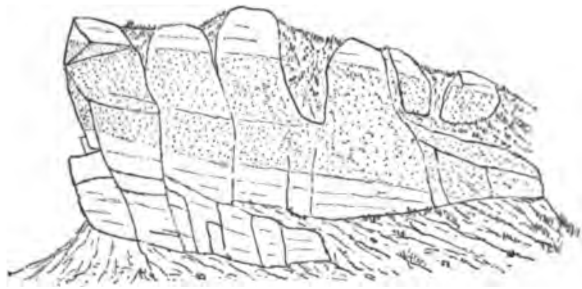
In the quarries along the line to Gouvy, the strike of the rocks is roughly parallel to the railway. The rock is a greyish compact grit or an imperfect slate, developing structure-planes only in weathering. On examination with the microscope it is seen to have similar characters to that by the Longwilly road. The general dip is about 20° north-westward or west-north-westward.

Towards the south, above a slope of débris, is a boss somewhat trapezoidal in shape, partly isolated by quarrying (fig. 4, p. 66), its stratification dipping gently south-eastward. Here the mineral changes are mainly restricted to a band roughly about 1 foot thick, while the adjoining layers are hardly more than indurated and of flinty appearance, with a greyish mudstone beyond, which at one part below is jointed into small rhomboids. In the hard bands, nearly vertical joints together with the almost horizontal bedding-planes form cuboidal, or, in the upper part, imperfectly spheroidal blocks which weather externally into platy flakes.

Taking a section across the layers from above downward, one finds:—A fine-grained quartz-felspar grit crowded with microliths,

with some graphite, biotite, pyrite, and iron-oxide. Next comes a banded rock, containing tufts of hornblende and of the supposed ottrelite intercrystallized, and abundant graphite. Small garnets begin to occur, and then become more numerous, being especially aggregated at the junction of adjacent bands. The garnets contain inclusions along crystallographic planes[1] (see fig. 3, p. 64); they are sharp-edged but often imperfect, especially where the lines of inclusions start; and they interfere mutually in their growth where a group has formed. Then comes the central banded rock more altered and rather clearer, with some hæmatite occasionally associated with the tufts, and containing but seldom mineral No. 17 (see p. 61), sometimes clinging to a well-formed garnet. The next band contains incipient hornblende or ottrelite, and incipient garnets. These are ill-formed and incomplete, being in places almost entirely occupied by interspersed crystalline grains. Then a blacker band containing graphite and incipient hornblende is followed by a greyish band including

Fig. 4.—*Band about 1 foot thick, containing garnets (often aggregated near planes of weakness) and hornblende or ottrelite; north-east of Bastogne, in quarries along the railway to Gouvy.*



[The rock is markedly stratified, and much jointed.]

much biotite. In the rock below, greenish films are abundant, opacite is less important, hæmatite or ilmenite-plates occur, and much biotite. Thus the rock, as we approach the central band, seems to show successively:—(1) minute greenish microliths, small biotite, scattered iron-oxide; (2) incipient hornblende or ottrelite with graphite; (3) in addition incipient ill-formed garnets; (4) hornblende (sometimes with ottrelite) better developed, and well-formed garnets.

Another patch of altered rock, seen on a joint-face,[2] measures about 18 × 3 inches, is irregularly wedge-shaped, weathering whitish,

[1] See A. Renard, Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) p. 15 & pl. i, fig. 1.

[2] The patch *a* represented in fig. 208 of Prof. Gosselet would agree somewhat in position with that above described, but it differs in shape and in being garnetiferous, and has probably been quarried away.

I found in a talus-heap near here a loose specimen containing garnets, some of which are about 5 mm. in diameter.

with green acicular hornblende often in tufts. The boundary seems clear, but under the microscope it is found to be a slightly brownish zone, containing scattered iron-stained films. Beyond this edge, the hornblende-tufts extend for a few inches within a strong indurated compact rock, which passes into a pale-grey dusty-looking grit. The patch is probably a section across the crust of a garnetiferous nodule, either still concealed or removed by quarrying.

Examination with the microscope shows tufts of hornblende, some biotite, iron-oxide, pyrite, and probably garnet, having a somewhat pegmatitic structure. In the grey rock (at about 2 inches from the patch) hornblende-tufts are absent, but biotite, iron-oxide, and small interstitial colourless garnet occur with greenish microliths. At about 9 inches are more abundant microliths, and larger and more numerous flakes of biotite, together with ilmenite, along the margin of an included fine-grained band.

It may be worthy of observation that the patches of altered rock are either black, containing carbon[1] and garnets accompanied by ottrelite or hornblende; or they are greyer, more compact, crowded with tufts of hornblende without the sharp-edged garnets. Both rocks are fine-grained grits, but the latter is rather coarser, with a texture approaching that of a quartzite.[2]

In each of the cuttings described the strata form a very flat, slightly undulating anticline, each cusp which points downward corresponding with a vertical joint, filled by secondary quartz, thinning out below.

III. Theoretical Considerations.

As to the causes which have affected these rocks, Prof. Gosselet maintains that the metamorphism is explained almost entirely by mechanical action, except in the sahlbands of the porphyroids and of the granite. The formation of new minerals was due, according to him, to the heat produced by arrest of movement, compression, and friction. The movements continued over a long period. Some rocks enclosing crystals produced by an earlier metamorphism were laminated by later pressure ('phyllades aimantifères' of Deville). In others which were already 'phyllades,' crystals were developed by a second metamorphism (as, for example, the ottrelite-schist of Bogny). The chapter which advocates this view[3] is a most valuable statement of facts and observations; but, for reasons of which the following is a summary, I am not convinced by the arguments:—

The author maintains that the 'corneite' is due to a more intense pressure, where the rocks are folded over to the north, yet he

[1] See Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 15, 17. The graphite, as described by Prof. Renard, is often disseminated as a fine dust.

[2] Compare the classification by Prof. Renard into quartzites, grits, and 'phyllades;' *op. cit.* p. 7.

[3] 'L'Ardenne,' 1888, ch. xxv. p. 759.

expressly says that the corneite is not found only in this position (*op. cit.* p. 771). Thus it seems more probably a coincidence, than a relation of cause and effect.

If the metamorphism of the 'corneite' were due to these causes, how could it be intercalated among grits which are not much metamorphosed (as at Serpont, etc.)?

It is difficult to understand how the movements which produce such undulations as are figured (*op. cit.* p. 769, fig. 208) could have caused the formation of the secondary minerals. These are often well-defined crystals, while in other districts far greater compression and folding has resulted only in microlithic development.

Even in the Ardennes, strata which are much more intensely contorted do not show any marked metamorphism.

No explanation is offered as to how pressure could have caused the metamorphism of 'nodules' or 'nodular patches' (*op. cit.* pp. 769, 789 & figs. 208, 216, etc.).

Prof. Gosselet refers the more marked metamorphism to movements of five different kinds :—(*a*) anticlinal, (*b*) synclinal, (*c*) near the sides of a fault, (*d*) along a fault, and (*e*) gliding-planes. But there can hardly be any locality here which does not exhibit one (or generally more) of these disturbances. Yet the chief secondary minerals are limited in their distribution.

When we consider what causes may have acted in the district, it is clear that the alterations include successive phases, one at least of which was due to pressure. Doubtless, as maintained by Dumont and by Prof. Gosselet, the pressure was of more than one epoch.

The altered rocks, so far as I have studied them, may be grouped as :—

1. Crushed quartzose grits ('arkose porphyrique'), with micromineralogical development (as, for example, Lamersdorf, Salm Château).
2. Rocks containing ilmenite, biotite, ottrelite, chlorite, with recrystallization of quartz. All these minerals are found over wide areas.
3. Garnetiferous and hornblendic rocks in limited patches.

Of these, the first and some of the second group doubtless exhibit pressure-effects, including possibly the development of ilmenite and of ottrelite; while the chlorite may be derived from biotite, or indirectly from hornblende.

Other results, such as the development of biotite; the recrystallization of quartz and felspar; and, even more important, the development of chiastolite described by M. Dupont, show such resemblance to the effects of somewhat slight contact-metamorphism that they are probably due to an igneous mass coming near to the surface in certain areas. We may compare the rocks with some of those from Andlau, or more closely with those from New Galloway collected by the late Samuel Allport.[1] In the latter, even in the less

[1] I have to thank Mr. L. Fletcher, M.A., F.R.S., and Mr. G. T. Prior, M.A., of the British Museum (Natural History), for allowing me to examine and compare the slides of these rocks.

altered examples, the biotite is generally more abundant, but the greatest amount is in one specimen from Libramont, and in all it is similar in character. Again, the small microscopic garnets in rocks from Libramont are rounded or subrotund, rather like those in contact-specimens from Glendalough and from New Galloway, although in the former the garnets have a grey centre and are contained in a fairly coarse mica-schist.[1]

Thus a resemblance is exhibited to contact-metamorphic rocks from other localities. As to the cause, it is true that, as Prof. Renard says,[2] the veins of porphyry and diorite in the Ardennes do not occur where the metamorphism is intense, but such intrusions as these would not cause much change. If the metamorphism in Brabant is due to them (as claimed by Dumont), it probably is only where the change is slight. Further, the existence of a subjacent igneous mass is surely not a 'gratuitous hypothesis,'[3] when evidence of its results can be given as stated above, and when in one district a granite has been shown to be exposed.

At the same time, the development of garnet and hornblende is so local and limited, that we seem forced to attribute them to a somewhat different cause. In regard to these, the following facts may be established:—

The stratification passing almost horizontally above the top of the 'nodule' belongs to a low, somewhat undulating anticline (although compression has given rise to slaty cleavage in some layers at a short distance). Thus the metamorphism cannot be due to folding or mechanical disturbance of the rocks, and the 'nodule' could not be a curiously contorted part of a band. Though the line of demarcation seems rather sharp in the field, and suggestive of a junction of an igneous and metamorphic rock, microscopic examination shows a gradual passage, with continuous lamination. The 'nodule' is part of the surrounding rock metamorphosed.

The 'nodule' is always very limited, generally a few feet across, and surrounded by normal, or but slightly altered, sedimentary rock. It is not likely to be a projecting knob of an ordinary contact-zone around a subjacent igneous mass, for such is nowhere exposed,[4] and its position within the surrounding rock makes this almost impossible.

Further, the secondary minerals differ from those of an ordinary contact-zone in certain respects, although resembling them in others. We note, for example: (1) the absence of any large andalusite; (2) the tufted growth of the hornblende; (3) the sharp outline of the garnets in a comparatively unmetamorphosed groundmass; (4) their peculiar internal structure; and (5) the frequent presence

[1] The garnets of the Brazil-Wood gneiss have a sharper outline, and exhibit internal cracks; but the rock is of a different type.

[2] See Bull. Mus. Roy. Hist. Nat. Belg. vol. i (1882) pp. 35, 36.

[3] 'L'Ardenne' 1888, p. 761.

[4] By the road from Bastogne to Longwilly no igneous rock is seen in the lowest part of the quarry, as already stated; and I searched the lower cutting by the railway, and the craglets south of the valley, but found none.

of carbonaceous material. Yet the recrystallized groundmass often resembles an early stage in contact-altered rocks. It frequently contains some of the characteristic biotite, which sometimes may be abundant even in a rock crowded with hornblende-tufts.

Thus we have to account for small limited patches often comparatively undisturbed, showing gradual alteration, with a marked line of change at one part, yet without any exposure of an igneous rock to cause the modification. I believe that the true solution will be found in the suggestion, made by Prof. Bonney in 1890,[1] that we see here results due to hot springs. They would modify the sedimentary strata, so that we should expect to trace a gradual transition. At the same time, a line of division would be marked around the central mass, often crossing the banding: just as a deposit from ordinary infiltration may end almost abruptly. The alteration would occur over limited areas,[2] which might appear in section as 'nodules,' or lenticular patches, or partial bands.

Mineral differences are sometimes exhibited along zones in the nodules, or along bands in the altered layers. This might be due to the marginal effects of the heated water. Even in a lava-flow minerals may be sublimed and deposited at one part of the layer. Thus Scrope pointed out that

> 'the specular iron, so frequently met with in lava-rocks, is evidently sublimed by [the intense heat of the lava] and .... is always found in the upper parts of the bed or current; while the lower parts of the rock .... have obviously lost all or the greater part of their iron by sublimation .... Or, as in many of the currents of Etna, the upper parts .... contain much specular iron, ... the lower and compacter division abounds in magnetic iron, in grains or octahedral crystals.' ('Volcanos' 2nd ed. 1862, p. 144.)

In the Ardennes 'nodule' the central and main part contains generally garnets, and often ottrelite, and is crowded with graphite. The last named substance (abundant only here) might have been deposited from the decomposition of a hydrocarbon contained in the waters of a hot spring.[3]

The peculiar character of the garnets (so different from those ordinarily found in schists or even in igneous rocks), their very

[1] 'On the Crystalline Schists & their Relation to the Mesozoic Rocks in the Lepontine Alps' Quart. Journ. Geol. Soc. vol. xlvi (1890) p. 214 note.

[2] Compare the cherty nodules of Stotfield which Prof. Judd attributes to 'purely chemical agencies,' Quart. Journ. Geol. Soc. vol. xxix (1873) p. 136. In Cornwall patches of altered rock occur, which also may be compared. Here the tourmaline, doubtless a result of infiltrating waters, has the same interrupted granular appearance as the biotite or hornblende; like these, it is sometimes developed along lines, and commonly forms tufts. I am indebted to the authorities of the Natural History Museum for facilities of studying slides from the Mousehole, Penzance.

[3] Just as the hot springs of California have deposited silica and sulphides of metals in accretions or disseminated through the rock, as described by J. A. Phillips, Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 390. See also Geol. Surv. California, vol. i (1865) pp. 92, 94. In slides at the Natural History Museum, belonging to the collection of that author, from a rock of Steamboat Springs (Nevada), an opacite-dust is scattered, reminding me of the distribution of carbon in the Ardennes rocks, although in the Nevada slide the opacite is probably a metallic ore.

regular shape, and regularly-arranged inclusions[1] point to some special action. Doubtless favoured by the slow growth of well-formed crystals, inclusions accumulated along crystallographic planes, and material from the groundmass was pushed to the exterior, so that a border of carbonaceous dust, or sometimes of secondary crystalline mineral, is found. Larger garnets or groups of them are sometimes developed along joints or planes of bedding. Either the infiltrating waters may have permeated more readily here, or crystallization may have started from the divisional surface.

The tufted growth of acicular or platy minerals (such as actinolite) has been shown in other rocks to be due to crystallization overcoming the resistance of a crushed or a fine-grained powdery mass.[2] But here we claim an initial aid to crystallization in the presence of heated waters. Even the friable earthy character of the interior might be caused by the later effects of vapours and solutions decomposing the mass.

Further, the numerous joints and the quartz-veins, narrowed downward towards the altered rock, might be due to chemical action. The expansion of the rock caused in such changes would slightly lift the overlying strata, forming a low arch, with joints as described above.

The solfataric theory may claim, to a certain extent, the support of Prof. Gosselet, since he emphasizes the important part which he believes that superheated water has played[3]; but I cannot adopt his view that the heat was developed through mechanical disturbances.

Thus we consider that this district exhibits modifications due to different kinds of action. Compression and folding, probably at more than one epoch, produced slaty cleavage, schistose structure (including that of the peculiar squeezed porphyroids), and even initiated the development of certain minerals. Contact-metamorphism, due to subjacent masses (like the granite which at Lamersdorf rises actually to the surface), probably acted over a certain area; while the local action of hot springs induced the development of the peculiar garnetiferous and hornblendic rocks.

Discussion.

Gen. McMahon remarked that the beautiful lantern-illustrations shown on the screen seemed to him to be quite typical examples of contact-metamorphism acting on fine-grained sedimentary rocks.

[1] We may compare the sharp form of couseranite within a slightly-changed ground; also the sharp-edged pyreneite (in a blackish limestone) which has similar regularly-placed inclusions. This latter is described by M. Ed. Mallard as corresponding to a group of orthorhombic pyramids, Bull. Soc. Minéral. Franç. vol. xiv (1891) p. 293.

[2] See T. G. Bonney, Quart. Journ. Geol. Soc. vol. liv (1898) p. 371; Proc. Roy. Soc. vol. lxiii (1898) p. 220; T. G. Bonney & C. A. Raisin, 'On Varieties of Serpentine & Associated Rocks in Anglesey' Quart. Journ. Geol. Soc. vol. lv (1899) pp. 294–97.

[3] 'L'Ardenne' 1888, p. 762.

Hot springs were potent factors in the metamorphism of rocks. He had studied their effects in the Himalayas, and found that the rocks in their vicinity—especially basalts—had been intensely metamorphosed. It was sometimes difficult, however, to distinguish between the results of contact-metamorphism and the results produced by hot aqueous agents circulating through rocks underground. Geologists were aware that the quartz of granite abounds in water-vesicles, and water was usually supposed to contribute by its presence to the fluidity of molten granite. An appreciable part of the contact-action of granite is due to the superheated water, or steam, emanating from the fluid magma; and the resulting metamorphism is sometimes not distinguishable from the action of water caught up in, or percolating through, sedimentary beds, and brought within the influence of underground heat and pressure. Some minerals, such as mica and hornblende, are known to be the products of contact-action and also of the simple percolation of water below the surface of the earth.

Prof. WATTS referred to the brief account, published in the Annual Report of the Geological Survey, of the metamorphic areas of the Isle of Man. These areas showed what appeared to be typical examples of contact-metamorphism associated with masses of granite and other intrusive rocks; but it has been found by Mr. Lamplugh that the metamorphism had no relation to the intrusive masses, indeed it was visible in the intrusive masses themselves. Minerals similar to those described by the Authoress occurred in the Isle of Man. The hypothesis of the action of mineral springs was one which would have to be carefully considered in the Isle of Man as well as at Bastogne.

The PRESIDENT and Prof. SOLLAS also spoke.

Prof. BONNEY, replying on behalf of the AUTHORESS, said that as the Isle-of-Man rocks, mentioned by Prof. Watts, were not yet really described, she could not be expected to refer to them. The Wicklow rocks he had seen, under the kind guidance of Prof. Sollas, and had examined with the microscope: but they were markedly different in more than one respect from those in the Bastogne area. Here the chief peculiarity was, that remarkably well-formed garnets occurred in a comparatively unaltered matrix. In ordinary contact-metamorphism (examples of which, as the Fellows had just seen, did occur in the Bastogne area) the garnets were seldom well-shaped, and only appeared when the matrix was greatly changed. So far as his own experience went, the Bastogne rock was almost unique, and its mode of occurrence was difficult to explain, either as the result of contact- or of dynamic metamorphism. As to the last, undoubtedly work produced heat; but the question was, how much? If the crushing was sudden, there might be a considerable rise of temperature, but then the vicinity should show great disturbance; if it were slow, there would be no effective rise of temperature.

6. *On the* Corallian Rocks *of* St. Ives (Huntingdonshire) *and* Elsworth. By Charles Bertie Wedd, Esq., B.A., F.G.S. (Read December 5th, 1900.)

[Communicated by permission of the Director-General of H.M. Geological Survey.]

(Map on p. 74.)

I. Introductory Remarks.

Lately while mapping the Ampthill Clay, I have been able to trace the Elsworth and St. Ives Rock for a considerable distance. I propose to give here a sketch of its outcrop and some account of exposures not previously noticed. The district here treated of is contained in the 1-inch quarter-sheets of the Geological Survey, Nos. 51 north-west & south-west (western part) and 52 north-east & south-east (eastern part), and in the New Series Map Sheet 187 (not yet published).

From Prof. Seeley's papers[1] the following description of the Elsworth Rock at Elsworth may be extracted:—

	Feet.
Rock-bed, like that below	1½
Brown-black clay, with *Ostrea flabelloides* (*Marshi*); this bed passes into sandstone	5
Dark blue homogeneous limestone, with ironshot oolitic grains, and iron-pyrites	3 to 7

It is known to occur throughout the village of Elsworth, passing southward under Ampthill Clay with three whitish-grey stone-bands.

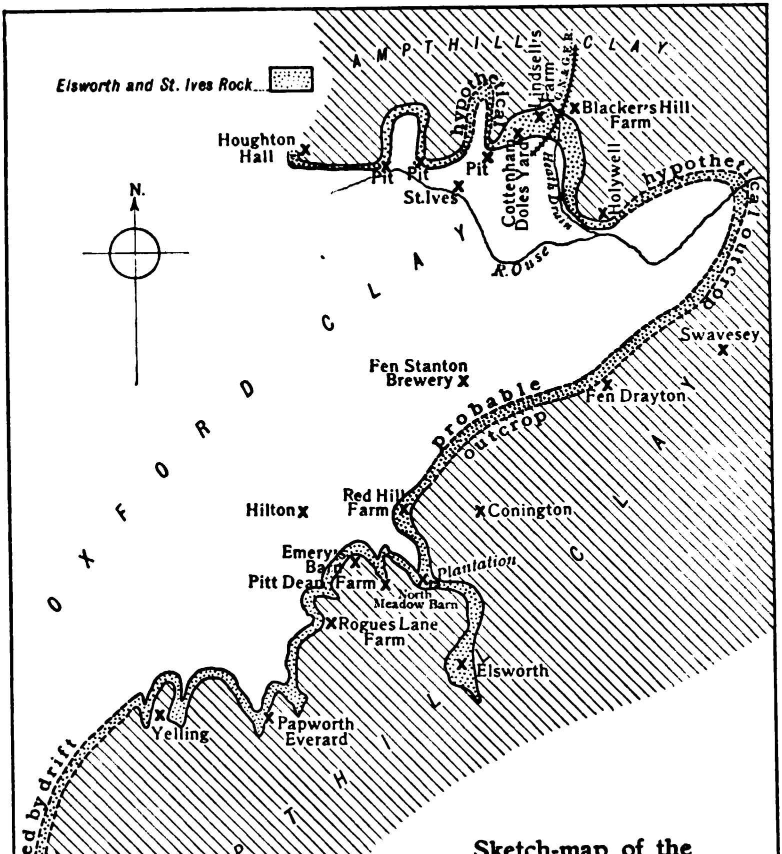
Prof. Seeley (*op. cit.*) also recorded rock-beds of type similar to the Elsworth Rock from wells at Bourn (3 miles south-south-west of Elsworth), Papworth Everard, and Conington; but he considered that the rock at the latter two places belonged to a lower horizon than that of Elsworth.

In a brickyard west of St. Ives a like rock has long been known (the St. Ives Rock); in other brickyards north and north-east of St. Ives beds of rock were noticed by Prof. Seeley as dipping eastward, and these he was inclined to think were continuous with the Rock west of the town.

A collection of fossils in the Woodwardian Museum, agreeing closely with the fauna of the Elsworth and St. Ives Rock, was supposed to have come from Holywell, but the occurrence of the limestone there was not definitely known. The late Thomas Roberts[2] mentioned a brown rock, as occurring at the northern end of Swavesey village, at a depth of some 20 feet. West of Bluntisham, north-east of St. Ives, a rock similar to that of Elsworth was

[1] Ann. Mag. Nat. Hist. ser. 3, vol. viii (1861) p. 503 & vol. x (1862) p. 98.

[2] 'The Jurassic Rocks of the Neighbourhood of Cambridge' (Sedgwick Prize Essay for 1886) publ. 1892, p. 23.



Sketch-map of the Outcrops of ELSWORTH and ST. IVES ROCK.

Scale: 1 inch = 2 miles

recorded by Prof. Seeley at the bottom of the railway-cutting. At Chettering Farm, near Stretham Fen, Elsworth Rock, associated with a sandstone band, was noted by Roberts in a well-boring. I have recorded Elsworth Rock at Upware, closely associated with the Upware Coral Rag and Oolite.[1]

No surface-exposure of the Elsworth and St. Ives Rock, except at these two localities, seems to be known in the district under consideration; but Mr. A. C. G. Cameron[2] noticed a rock at Hilton containing *Ammonites* and *Pholadomya*.

As to the mutual relationship of these rocks, Mr. H. B. Woodward[3] says:

> 'The Elsworth Rock was then (1862) considered to be the uppermost zone of the Oxford Clay; it is now regarded as equivalent to the St. Ives Rock, and both are grouped with the Lower Calcareous Grit, a view suggested by Messrs. Blake & Hudleston, and confirmed by Thomas Roberts,'

by whom a list of fossils from these rocks was given.[4]

On the published map of the Geological Survey the Elsworth Rock is not traced west of Elsworth, and the 'Lower Calcareous Grit' there represented appears to indicate an assumed higher bed: consequently it does not coincide with the outcrops here to be described.

II. Outcrops south of the Ouse.

The grey limestone weathers yellowish-brown, and disintegrates to a yellow calcareous marl with ironshot grains, which often may be easily traced at the surface. There are indications of a very hard blue band, apparently associated with the lower part of the rock, crowded with *Serpula* and generally full of *Exogyra nana*: it seems to be persistent as far as Upware, and is like the bed in the floor of the brickyard at Gamlingay.

About 1½ miles south of Croxton cross-roads, and 200 yards north of Abbotsley Brook, ferruginous and calcareous marl, with fragments of somewhat oolitic limestone, may be found in a ditch by the roadside. There is also a band of hard limestone, whitish when weathered, but bluish-grey when less altered. I found the following fossils:—

Pleurotomaria sp.
Exogyra nana, Sow. (extremely abundant).
Gryphæa sp. (few fragments).
Ostrea (*Alectryonia*) *gregaria*, Sow.
Pecten articulatus (?) Schloth.
Vermilia sulcata (?) Sow. (abundant).
Serpula gordialis (?) Schloth.

Although the oolitic type of the Elsworth Rock was only represented here by a few fragments in the marl, the hard limestone with *Serpula*, as also the great abundance of *Exogyra nana*, and the general assemblage of fossils, so closely recall the lower part of that Rock at Red Hill Farm, Hilton (described on p. 79) and elsewhere, that I have little doubt of its identity.

[1] Quart. Journ. Geol. Soc. vol. liv (1898) p. 601.
[2] Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. v (1895) p. 141.
[3] *Ibid.* p. 139.
[4] 'Jurassic Rocks of the Neighbourhood of Cambridge' 1892, p. 25.

Between here and Yelling the ground is Drift-covered, but in the middle of that village the high ground is intersected by a deep valley running from south to north. The northern part is in blue Oxford Clay. Farther south, immediately north of the road where it crosses the stream, near the Inn, is a fairly good section of grey ironshot oolitic limestone, weathering yellow, with many fossils, and seen for a thickness of 1 foot in the stream. It has a slight southerly dip, and is undoubtedly the Elsworth Rock. I obtained from it the following fossils:—

Ammonites (*Perisphinctes*) *plicatilis*, Sow. (as figured by D'Orb.).
Anatina sp.
Astarte mysis, Lor. & Pell.
Exogyra nana, Sow.
Gryphæa dilatata, Sow.
Hinnites sp.
Trigonia sp. (perhaps *Tr. clavellata*, Sow.).
Waldheimia (two species?).
Vermilia sulcata (?) Sow.

About 200 yards from the stream-section, a little east of south, is a well. The material here excavated—black laminated clay, with a thin stone-band like those that regularly occur a short distance above the Elsworth Rock—is certainly Ampthill Clay.

Some 900 yards east of Yelling Church the road crosses the southern end of another valley. About 140 yards north-west of the road a yellow-weathered limestone is seen in the stream, crowded with ironshot grains—undoubtedly Elsworth Rock. From here the Rock may be seen at intervals down the stream, for a distance along it of 650 yards from the road. At 180 yards below a bend where the stream turns northward the following section was noted:—

	Inches.
Boulder Clay.	
4. Brownish-black clay, with ironshot grains	3
3. Yellow, rotten, ironshot, oolitic limestone, with *Exogyra nana* and *Gryphæa* coated with *Serpula*	2 to 3
2. Brownish-black ironshot clay, with two very thin rotten ferruginous limestone-bands (the clay contains *Ostrea gregaria*, *Gryphæa dilatata*, and *Exogyra nana*)	20
passing down into	
1. Grey, ferruginous, ironshot, oolitic limestone, weathering yellow.	

The section 50 yards farther north was:—

	Inches.
4. Yellow-weathered ironshot oolitic limestone, disintegrated.	
3. Black laminated clay, with ironshot grains and *Ostrea gregaria*	12 to 18
2. Dark bluish-grey ironshot oolitic limestone	8 to 11
1. Light bluish-grey clay (Oxford Clay).	

The beds vary in detail: the dip also is variable, for the strata roll slightly. The following fossils were obtained from sections in this stream or from débris of the Rock in the bed of the stream:—

Ammonites (*Perisphinctes*) *plicatilis*, Sow.
Exogyra nana, Sow.
Gryphæa dilatata, Sow.
Ostrea (*Alectryonia*) *gregaria*, Sow.
Vermilia sulcata (?) Sow.

The *Gryphæa* and *Ammonites plicatilis* were abundant, and constantly overgrown with *Serpula*. The rock is exposed at intervals for nearly ¼ mile across the strike. Above the stream on the west the Rock may be traced farther north by the yellowish-brown surface-soil and rock-fragments.

About 1100 yards north-east of Yelling is a pond on the hillside. The excavated material contained blocks of yellow and whitish-weathered limestone with ironshot grains: here, and from oolitic fragments on the surface, I obtained:—

Gryphæa dilatata, Sow.
Ostrea flabelloides, Lam.
O. (*Alectryonia*) *gregaria*, Sow.
Vermilia sulcata (?) Sow.
Diastopora (*Berenicea*) *diluviana*, auct.

Farther east, on the road from Potton to St. Ives, about 150 yards south of the 6th milestone from St. Ives, I found a small exposure of 'ironshot' oolitic limestone and fragments of a hard band full of *Vermilia sulcata (?)*, containing also *Ostrea gregaria* and a spine of *Cidaris Smithii (?)* Wright. *Gryphæa* and *Exogyra nana* also occurred. North-west of here fragments of Elsworth Rock were found at the surface, for some distance on the flank of the high ground.

To the south-east a valley runs west of the church at Papworth Everard. South-west of the church a good section of Elsworth Rock was seen for about 100 yards in the stream; at one point it showed:—

	Inches.
Boulder Clay.	
Hard, grey, ironshot, fossiliferous limestone, about	16
Softer, marly, yellow-weathered limestone	10
Hard, grey, ironshot limestone, with many fossils, seen for...	6

The following specimens were obtained:—

Ammonites (*Cardioceras*) *excavatus (?)* Sow.
A. (*Perisphinctes*) *plicatilis*, Sow. (abundant).
Phasianella striata (?) Sow.
Pleurotomaria reticulata, Sow.
Astarte mysis, Lor. & Pell.
Exogyra nana, Sow.
Gryphæa dilatata, Sow. (abundant).
Lima rigida (?) Sow.
Pecten fibrosus, Sow.
Pholadomya æqualis (?) Sow.
Pleuromya recurva (?) Phill.
Vermilia sulcata (?) Sow.

Beyond the intervening high ground to the north-east, yellow marl with fragments of oolitic Elsworth Rock is again seen in a shallow valley along the north side of the grounds of Papworth Hall.

Thus, between Yelling and Papworth Hall four valleys cut southward into the northern slope of the Drift-covered high ground; the Elsworth Rock is exposed in these valleys, and its outcrop evidently loops northward in each case round the intervening eminences, before striking southward under Drift in the neighbourhood of Croxton.

On crossing some high ground north of Papworth Everard, yellow marl, with a few fragments of Elsworth Rock, was found

in a ditch a few yards west of Rogues Lane Farm on the road to Elsworth; and along the western slope of the high ground the Rock can be traced by fragments in the soil, becoming very numerous in the neighbourhood of an exposure 400 yards west-south-west of Emery's Barn, when I found in a ditch sections for 50 yards in a yellow ironshot limestone with *Ostrea flabelloides*, *Exogyra nana*, and *Vermilia sulcata (?)*. Blue Oxford Clay was seen lower down the slope. Thence the outcrop sweeps round the northern end of the hill on which Emery's Barn stands, closely following the 100-foot contour-line, as shown by fragments in the soil, with *Ammonites plicatilis*, *Gryphæa*, and *Serpula*.

East of this a valley runs south-south-eastward to Pitt Dean Farm; abundant fragments of the Rock occurred along both flanks of this valley. These contained *Ammonites cordatus* (fragment), *Belemnites* (fragment), and *Gryphæa* with *Serpula*. East of the valley, on the north-western projection of the high ground, about 600 yards north-north-west of Pitt Dean Farm, is an obvious outcrop of the Rock, yellowish-brown soil being full of large and small fragments of grey and yellow 'ironshot' oolitic limestone with *Gryphæa* and *Serpula*.

Along the north-eastern front of the high ground the outcrop can be traced by fragments in the soil for 1000 yards to North Meadow Barn. Here, halfway between Hilton and Elsworth, is a pond on a gentle northerly slope. In this pond the Elsworth Rock is fairly well exposed, and consists of yellow marl with yellow and grey ironshot limestone. I found at this locality *Pleurotomaria reticulata*, Sow., *Gryphæa*, *Pholadomya æqualis (?)* Sow., and *Pleuromya recurva*, Phill. The dip is obviously northward.

East of here the main outcrop bends abruptly northward, while a tongue of the Rock runs eastward and southward to Elsworth. Taking the latter line first, I found the rock at intervals in the ditch that runs from North Meadow Barn along the front of North Meadow Plantation. Hence it sweeps south-eastward and southward along the flat around the north-eastern corner of the hill. Near here, to the east, Thomas Roberts mentions a pond wherein a rock was to be seen, no longer visible, which he thought might be Elsworth Rock. It certainly is, for it is on the outcrop of that rock; the rock may be seen in the same field here and there, in the ditch which marks the parish-boundary. Southwards from here for 500 or 600 yards is a slight elevation obviously formed by the Elsworth Rock, as shown by fragments in the yellow soil and by ponds where the Rock may now be seen. The feature dies out southward. The limestone, denuded under Drift, may again be seen under a footbridge immediately north of the village of Elsworth.

Following the main strike of the Elsworth Rock from North Meadow Plantation across the flat, I found that it runs northward and then north-north-westward as far as Red Hill Farm, with an outcrop fairly well defined by numerous fragments of oolitic and

ferruginous limestone in a yellowish soil. A few yards east of the outcrop black laminated Ampthill Clay was seen in a pond. To the north Red Hill Farm stands on a ridge running roughly north-eastward and south-westward. Here is the rock noted by Mr. Cameron,[1] as mentioned on p. 75. I found it well exposed on the southern slope in a trench. It is a very hard bluish-grey limestone, with some calcite, full of *Serpula* and *Exogyra*, underlying a yellow marly soil which contains many lumps of ferruginous limestone and oolitic ironstone. I obtained:—

Ammonites (*Perisphinctes*) *plicatilis*, Sow.	*Gryphæa* sp. (abundant).
A. (*Cardioceras*) *cordatus*, Sow.	*Ostrea* (*Alectryonia*) *gregaria*, Sow.
Exogyra nana, Sow. (very abundant).	*Pecten articulatus (?)* Schloth.
	Serpula (abundant).

Immediately south of the ridge is a pond, apparently in Oxford Clay, in which *Gryphæa* and pyritized ammonites occur. On the top of the ridge, and on its northern flank, the Elsworth Rock is again recognized. On revisiting this locality I had the advantage of Mr. Keeping's company. He pointed out the close resemblance of the hard limestone to the band in the floor of the pit at Gamlingay, as well as to the lower part of the rock at Elsworth.

The outcrop probably does but cross this ridge, on the eastern part of which it seems to have passed under dark Ampthill Clay containing much selenite. It certainly has an easterly dip here. Conington, where Prof. Seeley records a rock-bed at a depth of 100 feet, is about a mile to the east. There can (I think) now be little doubt that this is the Elsworth Rock, a conclusion which also applies to the rock-bed seen in wells at Papworth Everard.

Beyond Red Hill Farm nothing is seen for a considerable distance: the outcrop of the Rock would naturally turn eastward on reaching the Ouse Valley. It is certainly absent on the east side of Fenstanton, where at the Brewery a boring has lately been made to a depth of nearly 200 feet. By the kindness of Mr. Burt, of Fenstanton, I was able to examine the material. No Rock was met with, and the clay is certainly Oxford Clay. I obtained the following fossils:—

Ammonites (*Peltoceras*) *athleta (?)* Phill.	*Avicula inæquivalvis*, Sow.
A. (*Cardioceras*) *cordatus*, Sow. (abundant).	*Gryphæa bilobata*, Sow.
A. (*C.*) *Mariæ (?)* d'Orb.	*Gr. dilatata*, Sow. (abundant).
A. (*C.*) *excavatus (?)* Sow.	*Pecten* sp.
Alaria trifida, Phill.	*Rhynchonella varians*, Schloth.

It has been mentioned (p. 73) that Thomas Roberts noticed a brown rock not far from the surface at Swavesey.

About 1100 yards west of the Castle Hill, Swavesey, in material dug from the drain, I found yellow marl containing several small fragments of yellow ferruginous limestone with *Serpula*, and have little doubt that the Elsworth Rock crops out here, approximately where it might be expected to do so.

[1] Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. v (1895) p. 141.

III. Outcrops north of the Ouse.

We may turn now to the St. Ives district, north of the Ouse. From the well-known exposure of the limestone, in the brickpit west of that town, I traced the yellow oolitic limestone westward along the escarpment as far as Houghton Hall. A fossiliferous rock had been noted here by Mr. Cameron. Appearances indicate that the outcrop probably strikes northward from here under Drift.

About 400 yards south-south-east of Houghton Hall, in material dug from the weathered rock, I found a block of hard bluish limestone full of *Serpula* and *Exogyra*, like that of Red Hill Farm and elsewhere.

At the eastern end of the section in the brickyard, the easterly slope appears to exceed the dip of the beds, and the outcrop is evidently cut back northward. About ⅝ mile farther north, 500 yards east-south-east of the first milestone from St. Ives on the road to Ramsey, on low flat ground, I found sections of the Rock in ditches. It consists of yellow marl and ironshot oolitic limestone, very fossiliferous, and contains:—

Ammonites (*Perisphinctes*) *plicatilis*, Sow. (abundant).
Gryphæa dilatata, Sow. (abundant).
Pecten articulatus (?) Schloth.
Pecten fibrosus, Sow.
Collyrites bicordata, Leske (abundant).
Pygaster umbrella, Ag.
Vermilia sulcata (?) Sow.

The brickyard north of St. Ives, mentioned by Seeley and Roberts, where similar rock was said to dip eastward under clay, is nearly ½ mile south-south-east from here, on higher ground. I found fragments of the same rock in the floor of this pit. Evidently the outcrop between the two brickpits forms a loop to the northward, as suggested by the surface-configuration (see map, p. 74).

Farther east is the third brickyard of Seeley and Roberts, north-east of St. Ives, where a similar rock was believed to occur in the floor of the pit. The brick-pit is excavated in the south-western flank of a tract of rising ground, with low ground on the north-west, west, and south. In the eastern side of the pit, and outside in the neighbouring field, are exposures of yellow marl and ferruginous somewhat oolitic limestone, with *Ammonites plicatilis* and *Gryphæa* encrusted with *Serpula*. The sections are obscure, but the Rock seems to be several feet thick, and must dip north-eastward here at a rather higher angle than usual, for immediately to the north black laminated clay is seen, markedly different from the blue clay worked in the west of the pit. This difference is recognized by the workmen, who state that the dark clay in the north-eastern corner is of no use for brick-making. The black clay is, I think, certainly Ampthill Clay. Yellow rock-débris are seen in the floor of the middle part of the pit, and must crop out again in the north side, for in the western part stiff blue Oxford Clay is worked, dipping slightly north of east at about 4°, as shown by a thin white stone-band; this is evidently lower than the yellow limestone. I

obtained from the workmen the following specimens dug out of the Oxford Clay:—

Eryma (?).
Ammonites (Cardioceras) cordatus, Sow. (abundant).
A. (C.) excavatus, Sow.
A. (C.) Mariæ, d'Orb.
A. (Oppelia) oculatus (?) Phill.
A. (Aspidoceras) perarmatus, Sow.
Belemnites hastatus, Montf.
Belemnites Oweni, Pratt.
Avicula inæquivalvis (?) Sow.
Gryphæa dilatata, Sow. (abundant).
Nuculana sp.
Protocardium striatulum (?) Sow.
Rhynchonella varians, Schloth.
Pseudodiadema versiporum, Woodw.

It seems, then, that the yellow oolitic limestone here separates the Ampthill from the Oxford Clay. The outcrop of the Rock is very narrow here, owing to its dip and the slope of the ground.

Some 200 or 300 yards north-east of the brickpit last described the rising ground is certainly capped by an outcrop of yellow ferruginous limestone; the yellowish-brown soil contains many fragments of it, and its outcrop must be much broader than in the brickpit. Less than 200 yards north of Cottenham Doles Yard yellowish-brown marl, with yellow ferruginous and slightly oolitic limestone, is seen in ditches. Many fragments of the Rock occur on the top and on the northern slope of the high ground, as far as Lindsell's Farm, ⅓ mile farther east. South and south-east of the farm abundant evidence of the rock is afforded by a trench along the eastern side of the railway, where yellow marl full of yellow and grey ferruginous oolitic limestone can be traced for some distance. I found here *Pleurotomaria* sp., *Exogyra nana*, and *Serpula*. Again in Heath Drain, where it is crossed by the railway, an exposure of the St. Ives Rock is seen, apparently dipping northward under Ampthill Clay. The Rock is, in part, a grey, strongly oolitic limestone, with ironshot grains and weathering yellow; in part also, a creamy-buff limestone, with few ironshot grains. I have seen a similar variation in the southern district; it seems to have been noted by Prof. Seeley at Elsworth. Fossils were abundant here, and I identified the following:—

Ammonites (Perisphinctes) plicatilis, Sow. (abundant).
Belemnites sp. (cast of phragmacone).
Pleurotomaria sp. (probably *Pl. reticulata*, Sow.).
Dentalium sp.
Pleuromya recurva (?) Phill.
Exogyra nana, Sow.
Gryphæa dilatata, Sow. (abundant).
Ostrea (Alectryonia) gregaria, Sow.
Collyrites bicordata, Leske.
Serpula sp.

The strike of the rock hereabouts bends abruptly southward, and the outcrop is unusually broad. Definite exposures require a width of at least 400 yards, and other indications suggest a still greater breadth. For some distance south of the road to Ely *Serpula*-coated oysters and fragments of the Rock are found at the surface. Near a pump 200 yards south of the road material dug from the drain shows many pieces of the Rock, large and small, in yellow marl. East of this drain high ground runs southward to Holywell, and on this high ground is a brownish-yellow marly soil strewn

with many pieces of yellow oolitic limestone, containing *Ammonites plicatilis*, *Pholadomya*, and *Gryphæa* encrusted with *Serpula*. The width of outcrop here is not less than 300 yards, and may be more, as the surface is obscured eastward by gravel.

From here to Holywell the high ground makes a strong feature on its western and south-western flanks, certainly composed in great part of the St. Ives Rock. I saw fragments of oolitic limestone in it near the eastern end of Parson's Drove, about ¼ mile north-west of Holywell Church. Farther south, below Manor Farm, springs are thrown out at the base of the feature: close to one of these, about 70 yards west of the churchyard, is a small exposure of yellow oolitic limestone. The Rock here forms the lower part of the escarpment, with probably Ampthill Clay above, the whole being capped with gravel.

It has been mentioned that there is in the Woodwardian Museum a collection of fossils believed to have come from Holywell, from a rock like that of St. Ives. I find that the southern part of the village of Holywell stands upon a gravel-capped escarpment of this Rock, a continuation of the above-described feature; some of the cottages are built directly on a yellow oolitic limestone. The last trace of the Rock that I have found, going eastward on the north side of the Ouse, is in the field behind the Inn at Holywell Ferry.

About a mile of fenland separates this outcrop from the place where I found traces of the Rock in a drain west of Swavesey. It is possible that the line of outcrop between these places crosses the river immediately east of here, under the fens. But the configuration of the ground, sloping east of the Ferry at probably a greater angle than the dip of the strata, makes it more likely that the outcrop runs some distance first northward and then eastward down the river-valley, before returning west of Swavesey on the south side.

IV. Conclusions.

I would here adduce the following stratigraphical evidence in support of the generally accepted view of the identity of the Elsworth and St. Ives Rocks. The limestone here traced from Yelling through Elsworth to Red Hill Farm, Hilton, is unquestionably one bed. It is equally certain that that traced from north-east of St. Ives to Holywell is one bed; neither is there room for doubt that the latter is the same as the rock north-west of St. Ives, for the intermediate exposures accord with the surface-configuration, the strata having a slight northerly and, in places also, a small easterly inclination. Now, west of St. Ives there is undoubted Oxford Clay below, and apparent Ampthill Clay above the limestone; north-east of St. Ives it has been shown that the Rock must separate Ampthill Clay from Oxford Clay. Farther east there is certainly Ampthill Clay above the limestone. Again in the south, at Yelling, there is certainly Ampthill Clay just above, and clay of

Oxford type just below the Rock; at Elsworth there is Ampthill Clay above the limestone; near Red Hill Farm there is Ampthill Clay above and apparently Oxford Clay below; while all the country immediately west of the Rock seems to be made up of Oxford Clay with abundant clean Gryphæas, and that on the east of blackish Ampthill Clay. Moreover, the position of the Rock north and south of the river is where it should be for one and the same horizon, if the general dip and the lie of the ground are taken into account.

It is probable that the Elsworth Rock in the Bluntisham railway-cutting, if it reaches the surface at all, does so as an inlier; and considering the small and locally variable dip of the beds, and the great area occupied by Ampthill Clay in the neighbourhood, such inliers are not improbable.

The Corallian strata of this district seem to show somewhat different conditions of deposition from those of the Oxford Clay. There is a marked contrast in the appearance of the large oysters in the Oxford Clay on the one hand, and in the Elsworth Rock and Ampthill Clay on the other. In the former they are usually clean and free from *Serpula*; while in the latter, more particularly in the Elsworth Rock, they are constantly overgrown, inside and out, with *Serpula*, and often bored. So, too, the large *Belemnites abbreviatus* at Gamlingay is often covered with *Serpula*, while the large belemnites in the Oxford Clay usually are not, if they ever are. This decided contrast seems to suggest a slower rate of deposition for these Corallian beds—a suggestion possibly supported by the generally bad state of preservation of other fossils in the Ampthill Clay of the district. Moreover, the frequent appearance of *Serpula* on shell-less casts of ammonites in the Elsworth Rock, and the wide persistence of the bed of *Serpulæ* previously mentioned, may point—the latter to a pause, the former to possible erosion and re-consolidation. It should be noted that the *Serpula*-bearing ammonite-casts are of the *plicatilis*-type, not older Oxfordian fossils.

In an earlier paper[1] I ventured to express the belief that the Elsworth and St. Ives Rock belongs to a somewhat higher horizon than the Lower Calcareous Grit. I would here point out that of the two zonal ammonites of the Corallian, the dominant form is of the *plicatilis*-, not of the *perarmatus*-type, equally in the stone-bands of the Ampthill Clay and in the Elsworth Rock itself. It should be mentioned that the *cordatus*-type occurs frequently in the lower part of the Ampthill Clay, but this ammonite has, I believe, often been recorded even high in the Corallian of other districts.

I am indebted to my colleagues, Mr. E. T. Newton, F.R.S., and Dr. F. L. Kitchin, F.G.S., for kindly determining some of the fossils here recorded.

[1] Quart. Journ. Geol. Soc. vol. liv (1898) p. 601

Discussion.

Prof. Seeley spoke of the difficulty with which the Author had met in mapping these thin and variable beds. The differences of interpretation from that originally made by the speaker were in matters of detail. He had been unable to trace continuity between the Elsworth Rock and the St. Ives Rock; and there were other stone-beds above the St. Ives Rock. By digging through the Oxford Clay with *Ammonites cordatus* and *Gryphæa dilatata* at Elsworth, he had shown that the Elsworth Rock was in the Oxford Clay. His fossils were placed in the Woodwardian Museum at Cambridge. M. Rigaux found a similar rock with similar fossils high up in the Oxford Clay of the North of France, though a little lower than the Elsworth Rock. He was unable to accept the present interpretation of the rock as Corallian, or as separating the Ampthill Clay from the Oxford Clay, as an interpretation warranted by the stratigraphical evidence. He found no stone where Oxford Clay and Ampthill Clay meet. The fossils of the Elsworth Rock, and still more of the St. Ives Rock, were interesting from the circumstance that, in so far as some species diverge from Oxford-Clay types, they resemble not only Corallian types, but Cornbrash forms as well.

Mr. H. B. Woodward observed that the Author had done good service in proving by careful 6-inch mapping the persistence of the Elsworth Rock and its connection with the St. Ives Rock. He suggested that the occurrence in the Elsworth Rock of the Lower Corallian *Ammonites perarmatus* and the Upper Corallian *A. plicatilis* might be taken to indicate the local blending of the two zones.

Mr. Hudleston observed that any attempt to relieve the monotony of the Fen clays by the discovery and identification of rock-masses within them was worthy of commendation. The Author, chiefly through lithological features, seemed to have recognized the well-known Elsworth or St. Ives Rock at so many points that he had been enabled to construct a ground-plan of the probable outcrop throughout a considerable area. The palæontological evidence offered to the meeting had been scanty; but in the provisional abstract there was some allusion to the fossils. They had already heard from Prof. Seeley, who first brought the Elsworth Rock under notice, that he regarded the fauna as uppermost Oxfordian. Judging from the ample list of Elsworth-Rock fossils published by the late Thomas Roberts, it was impossible to avoid the conclusion that the rock at Elsworth occupies a very low position in the Corallian Series. Indeed, whatever the Author's opinion on this point might be, his ground-plan or sketch-map proved the case pretty clearly. Here it is shown that the Elsworth Rock constitutes the base of the Corallian Series in that area, since it is represented as separating the Oxford Clay from the Ampthill Clay, which latter clay is well-known to be the equivalent of the bulk of the Corallian Series throughout the Fenlands.

The Rev. J. F. Blake remarked that, although there appeared to

be some divergence of view as to the exact horizon of the Elsworth Rock, the difference was really very slight; for, palæontologically, the lower part of the Corallian Series was Oxfordian. Ammonites of the type of *cordatus* (now called *Cardioceras*) are common to the St. Ives Clay and the Elsworth Rock, just as they are common to the Oxford Clay and the Lower Calcareous Grit elsewhere. Both rocks, in fact, are in the zone of *C. cordatum*. Ammonites of the type of *perarmatus* (now called *Aspidoceras*) have a somewhat wide range in time; but the particular species *perarmatus* characterizes the upper part of the *cordatus*-zone, and if it be present in the Elsworth Rock it practically fixes the horizon. Ammonites of the type of *plicatilis* (now called *Perisphinctes*) have a still wider range; and unless the actual species *plicatilis* (or, as it ought really to be called, *biplex*) were intended, the presence of the genus merely suggested rather an Oxfordian than a Corallian horizon, since, taken as a whole, there were more species of the genus in Oxfordian than in higher strata.

Mr. W. Whitaker also spoke.

The Author—after thanking the Fellows present for the kindly manner in which they had received his paper, and regretting that want of time had prevented him from laying all the available evidence before them,—in reply to Prof. Seeley and Mr. Hudleston, dwelt upon the great abundance of ammonites of the *plicatilis*-type in the Elsworth and St. Ives Rock, and on the calcareous bands of the Ampthill Clay, as distinguishing these beds from the Oxford Clay. He pointed also to the recorded occurrence of *Cidaris florigemma* in the St. Ives Rock. He believed that there was a lithological difference between the Ampthill and Oxford Clays, and would refer to the occurrence of typical Elsworth Rock, in which he had himself found *Cidaris-florigemma* spines, intimately associated with the Corallian limestones at Upware, in support of the Corallian age of the Elsworth Rock. In reply to Prof. Blake, he said that he had always believed ammonites of the *plicatilis*-type to be characteristic of the upper part of the Corallian.

7. THE UNCONFORMITY *in the* COAL-MEASURES *of the* SHROPSHIRE COALFIELDS. By WILLIAM JAMES CLARKE, Esq. (Communicated by W. SHONE, Esq., F.G.S. Read December 5th, 1900.)

THIS unconformity, locally known as the Symon 'Fault,' has received so much attention from geologists in the past, that it would almost seem superfluous to attempt any new study of the subject. So far back as 1861 it was brought by the late Marcus Scott before the notice of the Geological Society[1] in a very valuable paper, of the facts contained in which I shall here make use, though my inferences will be somewhat different from his.

In 1863, Mr. John Randall, in a joint paper with Mr. George E. Roberts, read by Sir Andrew Ramsay before the Geological Society,[2] showed that the same agency which created the Symon or Great East 'Fault' in the Coalbrookdale Coalfield had removed the whole of the older or lower beds of coal and accompanying seams of ironstone from the Devonian rocks several miles south of the above field, and that they had been replaced by two beds of inferior coal. Between the upper two of these seams was a bed of limestone containing *Spirorbis carbonarius* of sufficient thickness to repay burning for lime, the whole dipping apparently beneath the Bunter Sandstone, and reappearing in the same order, as Sir Roderick Murchison showed, a mile farther south at Cantern Bank and Tasley near Bridgnorth. Mr. Randall, in subsequent papers read before various scientific societies, and more particularly in his work on 'The Severn Valley,' published in 1882 (Madeley), showed that the same phenomenon of the Symon or Great East 'Fault' was observable all the way to the Forest-of-Dean Coalfield, and thence onward to the Bristol Channel.

Mr. Daniel Jones, F.G.S., in his observations on the Forest-of-Wyre Coalfield made in connection with the Coal Commission of 1871, and in various subsequent papers,[3] adduced much valuable evidence showing the replacement of the Lower Coal-Measures by the Upper, not in Coalbrookdale alone, but in all the Shropshire coalfields, laying special emphasis on the position of the *Spirorbis*-limestone-bed as forming a natural datum-line near the base of the Upper Measures.

The horizon thus denoted I accept as the base of the Upper Measures, but prefer not to trust to this limestone-bed as in itself a sufficient datum, for the following reasons: Firstly, it is liable to be confused with other *Spirorbis*-beds at a higher horizon in

[1] Quart. Journ. Geol. Soc. vol. xvii, pp. 457–67.
[2] *Ibid.* vol. xix, p. 230.
[3] 'Denudation of the Coalbrookdale Coalfield' Geol. Mag. 1871, pp. 200–208; 'On the Correlation of the Carboniferous Deposits of Cornbrook, Brown Clee, Harcott, & Coalbrookdale' *Ibid.* pp. 363–71; 'The Structure of the Forest-of-Wyre Coalfield' Trans. Fed. Inst. Min. Eng. vol. vii (1894), pp. 287–300, 577, & vol. viii (1895) p. 356.

the Upper (red) Measures, as at Hamstead Colliery; secondly, as pointed out by Sir Joseph Prestwich in his celebrated Memoir on the Coalbrookdale field,[1] it is never found in sinkings north and east of the Severn, nor is it found in Eardington, Highley, Billingsley, and other sinkings. I attribute this to the fact that, as it is a thin bed, and has perhaps a tendency to thin out eastward, its calcareous character has not been recognized by the sinkers. It may be wiser, therefore, to take the following group of strata as determining the base of the Upper Coal-Measure Series:—*Spirorbis*-limestone where present, Main Sulphur Coal, Brick and Tile Clays, Rough Rock, and Calaminear or Red Clay. Separating this from the denuded beds of the Middle Coal-Measures a thin white clay, 1 or 2 inches thick, is frequently met with. I am indebted to Mr. Daniel Jones's kindness for all the sections (except Highley and one of Billingsley) of the Forest-of-Wyre Coalfield that I have particulars of.

These Upper (red) Measures, whose basement-beds as just described form wholly or in part an easily recognizable horizon, have a much greater extension in the several coalfields of Shropshire than the productive Middle (grey) Measures which in the Coalbrookdale Coalfield and the Forest-of-Wyre Coalfield are found to underlie them. In the coalfields near the town of Shrewsbury they are the only series of Carboniferous rocks present, and rest immediately upon Cambrian or other formations older than the Carboniferous, the productive grey measures being entirely absent.

In the Coalbrookdale Coalfield the respective areas of Upper and Middle Measures are more nearly co-extensive, subject, however, to certain *lacunæ* in the Middle series which will be described more particularly on a subsequent page. In the Forest-of-Wyre Coalfield the Middle productive Coal-Measures are confined to the deeper portion of the basin; while the Upper (red) Measures extend marginally beyond the subjacent series, so as to repose directly upon Devonian or other ancient rocks, as in the Shrewsbury Coalfield.

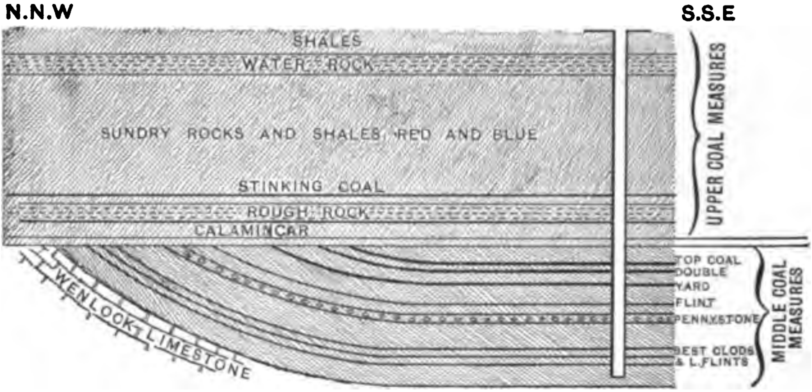
During a course of nearly twenty years' experience in the management of collieries at Madeley (Coalbrookdale Coalfield), I was impressed by the fact that whereas the seams of coal and ironstone in course of being worked rose at an inclination of 10°, 20°, 30°, and even 35° on the south-eastern flank of the Silurian limestone-anticline, which is an underground extension of Wenlock and Benthall Edges, the rocks on the surface immediately superjacent to our working (which were Upper Coal-Measure strata) were practically horizontal. I therefore plotted sections of our workings, of which the appended diagram (fig. 1, p. 88) shows the result.

Here then were some important facts: each workable seam, whether coal or ironstone, when worked in a north-north-westerly direction, or up the south-eastern flank of the anticline commonly called the 'Limestone Fault,' was found to terminate a few yards below the horizon where the shaft cut the Rough Rock with its

[1] Trans. Geol. Soc. ser. 2, vol. v (1840) p. 413.

underlying saem of Red or Calamincar Clay. These strata here constitute the basement-beds of the Upper (red) Series. The only possible interpretation of this fact appeared to me to be the supposition that the Middle productive Coal-Measures were tilted up,

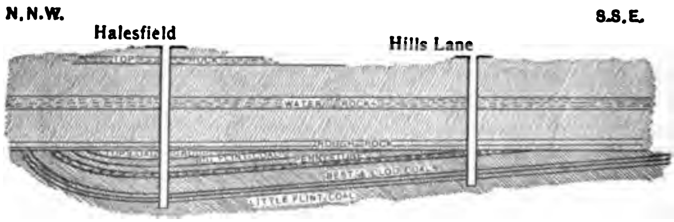
Fig. 1.—*Section in Madeley Court Colliery.*



[Scales: vertical, 400 feet=1 inch; horizontal, 10 chains=1 inch.]

and their edges denuded, before the Upper (red) Measures were deposited. In order to ascertain how far this supposition was true, it was necessary for me to trace the seams in the opposite or south-south-easterly direction and plot them in a similar manner; the following diagram (not drawn to scale) shows the result:—

Fig. 2.—*Diagrammatic section across the Madeley district, Coalbrookdale Coalfield.*



That is to say, the coal- and ironstone-seams were found to terminate against the base of the Upper (red) Measures in a south-south-easterly direction, as they did in the opposite direction—with this one noteworthy difference, that whereas the north-north-westerly rise was abrupt and at a gradually increasing angle, the rise in the south-south-easterly direction was so gradual and at so low an angle that the distance between the outcrops of some of the seams next in order one to the other would amount to 100 yards or more.

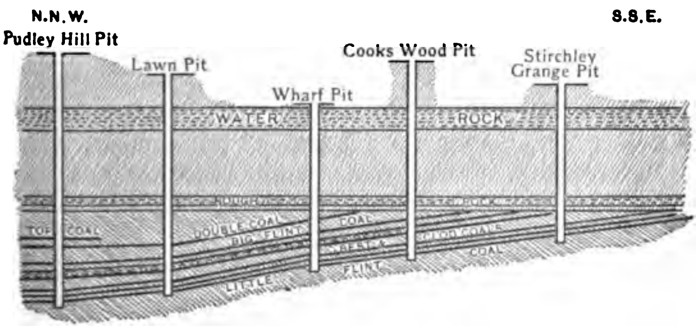
I then tried similar cross-sections of the ground, ranging from Ironbridge past Kemberton Pits in the direction of Shifnal, with a similar result; whence I concluded that the Madeley coal-basin consisted of an unsymmetrical synclinal fold of Middle Coal-Measures, having an east-north-easterly axis, the ridges or apices of the bounding anticlines having been denuded of their original covering of productive Middle Coal-Measures, and thus producing the phenomenon known as the Symon 'Fault.'

These observations not agreeing with the commonly received opinion, first enunciated by Marcus Scott in the above-mentioned paper, that the Symon 'Fault' consisted of a valley of erosion, I carefully went over his paper with the object of elucidating the cause of the inconsistency. I respectfully submit that the following is an explanation of it: Scott took as his datum-line the lowest workable seam of the older Measures, and the consequence is, that when the Upper Measures are plotted out, they are made in his section to occupy an unlikely position, as though they were deposited upon a slope. Scott evidently forgot the premiss upon which he had based his whole argument, for he said:—

'It therefore occurred to me that it would not be an unwarrantable geological liberty to assume that the coal-beds were originally deposited in an horizontal position, or nearly so' Quart. Journ. Geol. Soc. vol. xvii (1861) p. 460.

Had he kept to this rule, he would have been led to take as his datum-line the basement-beds of the Upper Coal-Measures, and his sections would then have given him a portion of another syncline identical in form with, but larger in extent than, the Madeley syncline. The following figure shows Marcus Scott's sections

Fig. 3.—*Section taken from Marcus Scott's paper, but redrawn with the basement-beds of the Upper Coal-Measures as a datum-line.*



[Scales: vertical, 600 feet = 1 inch; horizontal, 40 chains = 1 inch.]

plotted to the new datum-line, with the exception of Halesfield, which is in the Madeley district.

This syncline is both wider and deeper than the Madeley syncline,

and if the section be extended so as to include the Hadley and Wombridge district, which is the deepest portion and consequently forms the axis of the syncline, three more seams of coal and two more beds of ironstone (namely the Fungus Coal Group, belonging to the Middle Coal-Measures) are found, over and above those met with in the axis of the Madeley syncline. The extension of this section beyond Hadley, so as to include the other and steeper horn of the curve, is prevented by the interposition of the north-western boundary-fault of the Coalbrookdale Coalfield, cutting off the coal-seams and bringing in the Bunter Sandstone in their place. This fault, with a downthrow of great extent, is a continuation of the Church Stretton Fault. Fortunately, however, the direction of this fault, and the anticlinal axis of which we are in search, do not run quite parallel, but intersect at a very acute angle in the neighbourhood of Donnington Wood. Thence past Muxton Bridge to the trial-pit at Lilleshall, the Middle Coal-Measures are found to rise sharply north-north-westward, as in the Madeley district.

At Donnington and Muxton Bridge, however, the Upper Coal-Measures are wanting, having been denuded away, but at Lilleshall Trial Pit, Granville, Woodhouse, and Stafford Pits they are in their usual position. Therefore, a section drawn through the Coalfield, from Lilleshall across these pits to the Stafford, again shows the same unsymmetrical syncline as that exhibited in our former sections, but on a larger scale.

In passing, I wish to make the suggestion that the Granville section, the best developed in the Coalbrookdale Coalfield, does not (in my opinion) represent the fullest development of the Middle Coal-Measures originally attained in Shropshire. I surmise that originally this coalfield approximated very nearly to the extraordinary thickness of the North Staffordshire Coalfield from the Bassey Mine downward. The evidence for this view is not, I confess, conclusive, resting chiefly on these two facts: firstly, the gradual increase in number of the beds of coal and ironstone coming in under the Upper (red) Measures as we proceed from south to north; and secondly, the existence of a *Spirorbis*-limestone above the Bassey Mine at Fenton.

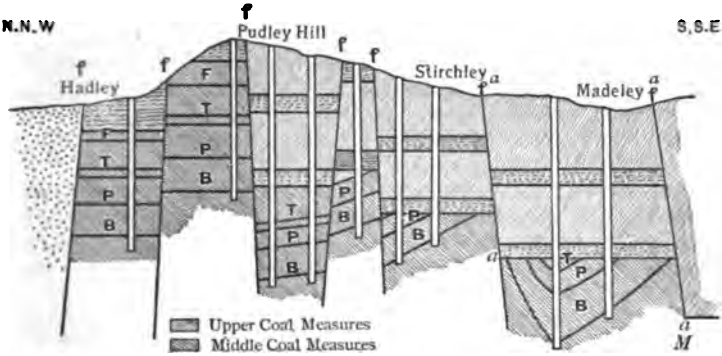
Retracing our steps to the Coalbrookdale field we find another little coal-basin, namely, the Inett-Caughley basin, again forming an unsymmetrical syncline on a small scale, of exactly the same type as that at Madeley. The Upper (red) Measures cut out all the productive Middle Coal-Measures on the ridges of the containing anticlines. The bounding anticlines were all mentioned by Prestwich in his famous memoir on the Coalbrookdale Coalfield, and it appears to me singular that their full significance has not been realized; to my mind they constitute the key to the whole problem.

Passing over the intermediate ground between here and the Forest-of-Wyre Coalfield, two facts are worthy of notice: firstly, that at Eardington Deep Pit the Upper Measures repose directly on Devonian strata, and if my theory is correct we must regard this

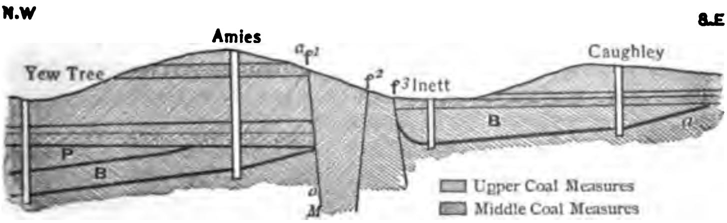
pit as being sunk on the top of a broad anticline. On the other hand, the outlier of older Coal-Measures on the Brown Clees would point to the surmise that there we are in the axis of a syncline; but denudation having in this district operated in comparatively recent times, the data are not very plentiful, and I do not insist.

Coming, however, to the Forest-of-Wyre Coalfield and its outlier of older Coal-Measures on the Titterstone Clee Hills, we undoubtedly again meet with the same phenomenon as that noticed in the

Figs. 4 & 5.—*Sections showing the present position of the strata, the post-Carboniferous faults being re-inserted.*



[Scales: vertical, 600 feet = 1 inch; horizontal, 2 miles = 1 inch.]



a = anticlines.
f = Faults.
F = Fungus Coal Group.
T = Top Coal Group.
P = Pennystone Group.
B = Best Coal Group.

[The horizontal scale has been enlarged to 2 inches to the mile in fig. 5, in order to show the Madeley and Swinney Faults (f^1 & f^2); f^3 is No. 58 in Prestwich's Map and Memoir.]

Coalbrookdale field, as shown by the dips on the Geological Survey Maps. This syncline in my opinion (an opinion which I deduced from its general direction, the similarity of the coals at Highley to those at Cannock, and the subjacent formation in both cases being red Devonian strata) continues to Huntington in Staffordshire.

This syncline is bounded on its north-western side by an anticline ranging from Titterstone Clee Hill through Billingsley, and, I

assume, continued underground, until a similar ridge is met with at Huntington Colliery. On the south-eastern side it is bounded by the Trimpley anticline through Shatterford and Compton, as shown by Mr. T. C. Cantrill.[1] There, however, we meet with certain phenomena not found in the Coalbrookdale field.

Firstly, there is, as pointed out by Mr. Daniel Jones, a series of unproductive measures, intermediate between the Middle productive grey Measures and the Upper non-productive red Measures (whose basement-beds are here represented by the rocks and marls underlying the Main Sulphur Coal). As these measures are very thick in the Highley and Shatterford Pits, and on the other hand very thin or non-existent in the Harcott and Billingsley pit-sections, between which two groups a fault exists, it would seem as though this fracture had commenced before the Upper (red) Measures were deposited, whereas in the whole of the Coalbrookdale field I know of no fault that has occurred before the Upper Coal-Measures were first deposited, excepting of course minor slips. They all seem to be post-Carboniferous in date, affecting Upper and Middle Coal-Measures equally.

Secondly, on the north-western flank of the Trimpley-Shatterford anticline the Upper Coal-Measures have been tilted to a greater extent than the Middle Series, owing, as I suggest, to volcanic action continued in Permian or post-Permian times.

Summarizing the foregoing observations, we find in the Middle (productive) Coal-Measures of Shropshire a series of undulations diminishing in amplitude and length as we proceed from the north-west towards the south-east. The axes of these undulations have a general east-north-easterly direction, the synclines being unsymmetrical in form, having steep slopes on the north-north-west and rising at a very small angle to the south-south-east, as though the force of the undulatory movement originated in the north-west and was directed towards the south-east, the apparently rising ground of the Shatterford district forming a point of resistance. Between these synclines are a series of anticlines, from the tops of which all the productive Coal-Measures were removed, and the subjacent formations laid bare before the Upper (red) Measures were deposited. Such, I submit, is the nature of the unconformity which exists between the Upper and Middle Series, and constitutes the so-called Symon 'Fault.'

But the existence of undulations of this nature in the Middle Coal-Measures is not confined to Shropshire. Commencing with the Pendle line of upheaval, which runs past the mouth of the Dee through Ormskirk to Pendle Hill, and forms the northern boundary of the Lancashire Coalfield, we pass firstly the Rossendale anticline; then one in connection with the Great Bala Fault, dividing the Flintshire from the Denbighshire Coalfield, and visible at the surface at Caergwrle Castle and Caer Estyn, the coals on the south-eastern flank of which it has been the writer's privilege to

[1] 'A Contribution to the Geology of the Forest-of-Wyre Coalfield' Kidderminster, 1895.

work, the coal-seams lying both as to inclination and strike exactly the same as the coals at Madeley (Shropshire). Then there is the well-known Staffordshire anticline, running from Mow Cop past Madeley; and others are more obscurely evidenced in the district about Shrewsbury, Haughmond Hill, and Childs Ercal. All these have the same general east-north-easterly direction as those in Shropshire.

From this I infer that they were formed at the same time, under the same conditions, by the same causes, and that we must therefore regard the region comprised between the Pendle range on the north, the Shatterford anticline on the south, the Welsh Hills on the west, and the Pennine Chain and its prolongations on the east, as one and the same coalfield, with the same geological history.

Prof. Hull, in his 'Coalfields of Great Britain,' has gone fully into this matter, and there claims to have been the first to show, in his paper read before the British Association at Liverpool in 1870, the pre-Permian age of these flexures, but dates them as post-Carboniferous. It is a difficult task to enunciate a view contrary to so eminent an authority, but I respectfully submit that the evidence which I have adduced goes to establish that the stratigraphical break (in Shropshire at any rate) was *during* Carboniferous times, *after* the deposition of the *Middle* Coal-Measures, and *prior* to the deposition of the *Upper* (red) Measures.

Should this contention prove to be correct, it will then follow that in searching for coal below the Triassic rocks, the presence of the Upper series of Coal-Measures forms no guarantee that the Middle and Lower productive series will be present underneath. The source from which guidance is to be obtained is the presence of synclines in the Middle and Lower Coal-Measures in the collieries in operation marginal to the Triassic area. For this purpose all sections of borings and sinkings should be carefully recorded, and in plotting out these sections all faults of later date than the Upper Coal-Measures must be carefully eliminated.

On both the eastern and western sides of the above-mentioned region the exposed coalfields now in operation are believed, on fairly good grounds, to be separated from their underground continuations under the Triassic area by downthrow faults of considerable displacement. The coal under these Red Beds will be struck only at a very great depth, and every unsuccessful attempt will entail an enormous loss. In order to avoid such a loss, too much pains cannot be taken to arrive at the exact configuration of the seams in the marginal workings.

Discussion.

Prof. Lapworth congratulated the Society upon the clear and business-like manner in which the Author had laid his facts and conclusions before the meeting. The general structure of the Coalbrookdale Coalfield had been more or less familiar to geologists since the publication of Prestwich's fine memoir upon it in 1840.

The remarkable phenomenon of the Symon 'Fault,' as originally described by Marcus Scott, had keenly interested geologists from the first; and his suggestion that it was due to a mere local denudation-valley had since been largely corrected and amplified by Mr. Daniel Jones. But the Author of the present paper was the first to demonstrate, by actual plotted sections, that in the Coalbrookdale Coalfield the Symon 'Fault' is a phenomenon of folding as well as of broad denudation.

The transitional period of time between the deposition of the typical Middle and Upper Coal-Measures had long been recognized by Midland geologists as one of more or less regional upheaval and denudation; and abroad this special inter-Coal-Measure period of crust-movement was described by Prof. Suess and others as one of the grandest in geological history—namely, that of the great Hercynian movement: the mountain-making period of the Harz, the Alleghanies, and the Armorican chains.

It was of extreme interest to note from the Author's sections that the Coalbrookdale crust-creep, although Armorican in date, so to speak, was Caledonian in direction. There was much to be said also in favour of the Author's opinion that other parallel and similarly denuded folds of Caledonian trend affect the Middle Coal-Measures under the Red Rocks of the Midlands, and that consequently the presence of Upper Coal-Measures affords no certain guarantee that Middle Coal-Measures actually occur below. Unfortunately, this was only one danger among many. The Coal-Measure Period as a whole was one of crust-movement, and there is evidence of this in the four usual directions. Though the predominant movement in the Coalbrookdale Coalfield was from the north-west, in the Bristol-Channel region the Armorican creep made itself most felt; whereas in other parts of England, as locally in the Midlands, sometimes the Charnian, and sometimes the Pennine creep has the greatest effect. Careful observations and conclusions, such as those of the Author, made by mining-engineers and bringing out the dominant local directions of movement, are certain to prove of great assistance in opening out the hidden coalfields of our country.

Prof. Groom expressed his gratification that the Author's results were in harmony with the views which he (the speaker) had previously expressed. He congratulated the Author on obtaining a much-needed clue to the age of the north-easterly and south-westerly folds of the Welsh Border. It was necessary, however, to recognize that all the British folds parallel to this direction were not of the same age. A considerable part of the British Isles appeared to have been built up at different periods by successive addition of zones of plication, each lying south-east of its immediate predecessor.

The Rev. J. F. Blake enquired whether there was any *Spirorbis*-limestone, or underclay beneath the coal in the Upper Measures here, since otherwise Prof. Hull's suggestion of their possible classification with the Permian might be correct. But, assuming them to be true Upper Coal-Measures, the Author had drawn them horizontal and spoken of a plane of denudation of the Lower Measures; while

Marcus Scott had represented the line of junction of the two series as met with at various depths along a valley-like line. This locality had been already quoted as affording evidence of a period of mountain-upheaval in the middle of Coal-Measure times, and the Author's account was more favourable to this than Scott's; but in any case the bendings were comparatively feeble. The other localities quoted afforded very little satisfactory evidence of any great upheaval at this period, as was shown by the speaker *seriatim*; and there was no proof that the patches in relation with the Haffield Breccia belonged to the Upper Coal-Measures—or had been originally deposited where now found. On the other hand, the neighbouring Upper Coals at Abberley are themselves inverted, as pointed out by Murchison.

The authority of Prof. Suess had been invoked for the existence of an upheaval at that time throughout Europe; but the upheaval to which Suess referred, as was evident from the context, was one at the end of the Carboniferous Limestone Period—his 'Upper Carboniferous' embracing the whole of our Coal-Measures. If, therefore, there were three great upheavals—at the beginning, middle, and end of the Coal-Measure Period—that period must have been one of great disturbance, alternating with the most tranquil conditions necessary for the formation of coal, a supposition which was scarcely credible.

Prof. Watts pointed out that Scott's paper was founded on the interpretation of a faulted and disturbed district. He interpreted it on the assumption that the Middle Coal-Measures were horizontal; the present Author supposed that the Upper Coal-Measures were horizontal. It was significant that in these two cases theoretical results of far-reaching importance were brought out from the careful consideration and plotting of the sections obtained during colliery-operations.

Prof. Hull also spoke.

The Author said that these Upper (red) Measures extended from at least the Wrexham district on the north, to the Forest of Wyre on the south, as well as to North and South Staffordshire. The Main Sulphur Coal, the only workable seam in them in the Shropshire district, is found in the Shrewsbury, Coalbrookdale, and Forest-of-Wyre fields. As the Author believed, it had its representative in South Staffordshire; it was a true coal-seam, with its own proper underclay, and must have been deposited horizontally. The inter-Carboniferous folds, though very important practically and economically, could not be called 'mountains,' as their greatest amplitude was about 160 yards, the thickness of the productive series. Whether these Upper (red) Measures ought to be classified as Permian, the Author was not competent to decide on palæontological grounds, but they undoubtedly contain numerous thin coal-beds.

The Lower or Gannister Series was not represented in Coalbrookdale, unless the Little Flint Coal and the immediately contiguous beds could be regarded as such. The Carboniferous Limestone and Millstone Grit also thinned out and died away here.

8. *On the* Upper Greensand *and* Chloritic Marl *of* Mere *and* Maiden Bradley *in* Wiltshire. By A. J. Jukes-Browne, Esq., B.A., F.G.S., and John Scanes, Esq. (Read December 19th, 1900.)

[Plates III–V.]

Contents.

I. Introduction.

The object of this communication is to give some account of the geology of a little known district on the borders of Wiltshire and Somerset; a district which includes the parishes of Mere, Stourton, Kilmington, Maiden Bradley, and Horningsham. This area is included in Sheet 19 of the old 1-inch Ordnance Map and in Sheet 297 of the new series of maps.

It is a high watershed-area, from which streams flow into four different rivers. At Stourton are the sources of the Stour which flows southward; at Kilmington is a bourn which flows eastward into the Deverill Brook, and is consequently one of the sources of the River Wily; near Maiden Bradley are springs from which watercourses run northward into the Frome; while of the waters which issue from the western border of the high ground, some join the Frome and others are tributaries of the Brue.

The greater part of the area is occupied by sandy beds of Selbornian age, usually known as Upper Greensand; these form a high plateau, which rises gradually westward and terminates in a bold escarpment, overlooking the lower ground, formed by the outcrop of the Oxford Clay and Lower Oolites, in the valleys of the Brue and the Frome. The summit-ridge of this escarpment rises in several places to over 800 feet, the highest point being Alfred's Tower, marked as 854 feet. Eastward the Greensand plateau slopes below the Chalk, which forms a second bold, but more broken, escarpment rising to nearly the same height, and in one advanced knoll or promontory to 945 feet.

This district was mapped by the officers of the Geological Survey in 1845, and the mapping has not been revised since; but, from a revision of the adjoining tract to the north in 1889, it became known that the Gault was continuous beneath the Upper Greensand, and consequently this clay was shown on the recent Index Map of the Geological Survey.

The base of the Chalk is not very accurately indicated on the

old Geological Survey map; and as one of us (J. S.) has practically re-surveyed this line from Maiden Bradley to Mere, we are able to present a corrected version of it, based on the new 1-inch map (Pl. III). Our map also shows the upper limit of the Lower Chalk, that line too having been traced by the author resident at Maiden Bradley.

The southern boundary of the Cretaceous area is a line of fault running by Bourton, Zeals House, Mere, and West Knoyle, bringing the Greensand and Chalk against Coral Rag and Kimeridge Clay.

Nearly all the field-work on which this paper is based has been carried out by Mr. Scanes, acting under the guidance of Mr. Jukes-Browne, to whom he sent measurements of each section, accompanied by samples of every bed measured. Mr. Scanes has also spent much time in collecting carefully and separately from such beds as contained fossils; and examples of all that were found have been sent to Mr. Jukes-Browne, by whom they have been identified so far as present knowledge permits, but some of the species appear to be new, especially among the gasteropoda. From these data the following account of the exposures and the lists of fossils have been drawn up.

II. General Succession in the District.

The general structure of the district was well described by a correspondent of Fitton's, who printed the account, with a sketch-section and some comments of his own, in his well-known memoir on the 'Strata between the Chalk & the Oxford Oolite.'[1] It appears that a well had been sunk near the foot of Whitesheet Hill, and that the well-sinker gave the following account of the beds traversed:—

	Feet.
(*a*) Malm, like the Chalk-Marl of Lewes in Sussex, full of the characteristic fossils: sharks' teeth in great abundance	100
(*b*) 'White stone,' so-called, but in reality rather grey or green, full of ammonites, many of which preserve their iridescent coats	4
(*c*) 'Chert,' at the lower part rubbly, and there the water rose	30
	134

His *b* is evidently the Chloritic Marl and *c* the Chert-Beds. The underlying sands are described as loose, but containing

'huge concretional masses of stone of similar composition (? the Cowstones of the Devonshire coast).'

The sands are stated to rest upon clay, and Fitton suggests that this clay must include the Gault.

To the foregoing account we may add that the easterly dip is greater than that shown in the section given by Fitton; that

[1] Trans. Geol. Soc. ser. 2, vol. iv (1836) p. 256.

the Gault is certainly present, and is probably from 80 to 90 feet thick; that above the Gault is a dull grey micaceous and calcareous Malmstone, which passes up into fine grey micaceous sand; and finally, that there is glauconitic sand which weathers yellow or buff.

Near Maiden Bradley the easterly dip is modified by the anticlinal flexure of the Warminster district; and, as a consequence, the local dips have a southerly direction.

The general succession below the outcrop of the Melbourn Rock is as follows:—

		Feet.
Lower Chalk with hard Chloritic Marl at the base ...		200
Selbornian.	Sands with calcareous concretions	3 to 8
	Sands with siliceous concretions (cherts)	20 to 24
	Coarser green sands .... about	15
	Fine grey and buff micaceous sands ...... „	120
	Sandy Malmstone .... „	15
	Dark-grey marl and clay (Gault)	90
Kimeridge Clay, Corallian, and Oxford Clay.		

III. Exposures of Gault.

Although the Gault does not exactly come within the scope of this communication, it will be as well to mention such indications of its existence as we have seen, because it forms the lower part of the Selbornian Stage, though it is only about half as thick as the Upper Greensand into which it passes.

The Gault is nowhere well exposed, for it only comes to the surface in a narrow band along the steep slope of the outer escarpment, and again as a small inlying tract at the bottom of the deep valleys which trench the Greensand plateau west of Stourton.

Its base has not been seen, for, as it lies on Oxford Clay, it makes no feature. Its highest part, consisting of a grey or greenish micaceous clay, has been seen in places beneath the Malmstone; this seems to pass down into a stiff dark-grey clay, which is almost black when wet.

In Bradley Wood, about a mile north-west of Maiden Bradley, springs seem to be thrown out at or near the base of the Gault. Near the Keeper's Lodge, and just below the 500-foot contour-line, there is said to be blue clay beneath 3 feet of soil; while north of Katesbench Farm, at about 550 feet, Malmstone is seen.

In the valley north of Maiden Bradley, and immediately below the outcrop of the Malmstone, about 10 feet of dark-grey clay was exposed by the fall of a large tree.

IV. Exposures of Malmstone and Micaceous Sands.

The main outcrop of these beds is also a narrow tract, despite their great thickness; they form the steeper part of the slope of the escarpment, and exposures in them are few and far between.

The most southerly place where we have seen them is on Kingsettle Hill, south-west of Alfred's Tower, where a sand-pit exposes about 40 feet of buff-coloured sand. The Malmstone is not seen, but there is wet ground near Hilcombe Lodge at

about 680 feet, so that its base is probably at or near that level. The summit of the hill by Alfred's Tower is 854 feet, but as there is some thickness of chert-rubble here, the combined thickness of Malmstone and sand is not likely to be more than 160 feet and is possibly less.

At the north-eastern end of Kings Wood Warren, west of Kilmington, are two spring-heads in both of which Malmstone is exposed, resting upon a greenish micaceous clay (Gault). The water from these springs supplies the town of Bruton, and the level from which they rise is about 660 feet. The high ground north-west of them rises to over 800 feet.

Farther north, in West End Wood, are several springs at a level of about 640 feet. Above them, on the 700-foot contour, is a sand-pit showing about 30 feet of grey glauconitic sand, with fragments of *Neithea quadricostata*; but this sand may be part of a slipped mass. Half a mile east of this, where three roads meet, is a quarry showing the lower part of the Chert-Beds, broken up *in situ* and overlain by 1 or 2 feet of red Clay-with-Flints; the level here is 778 feet, so that apparently there is not more than 130 feet between the base of the Malmstone and the Chert-Beds, unless the dip is here steeper.

Northward the ground rises to over 800 feet, and there is another quarry in the Chert-Beds on the 800-foot contour-line; while down the slope to the westward in Witham Park Wood there is a weak spring (at about 650 feet) showing bluish-grey micaceous sandy clay, which we take to be the passage-bed from Gault to Malmstone. Here again, allowing for dip, there is room for about 140 feet of Malmstone and sand between the spring and the base of the Chert-Beds.

North of Maiden Bradley and a little north of Katesbench Farm, Malmstone is exposed in the bank of a pond at a level of between 560 and 570 feet; about 3 feet of it is seen, and it has yielded *Ammonites rostratus*, *Pleuromya mandibula*, and some other fossils.

Fossiliferous Malmstone is also exposed at several of the spring-heads near Dunkerton cottages, in the valley north of Maiden Bradley; and in 1899 the fall of a tree above the spring, 200 yards north of the cottages, allowed the following succession to be seen:—

	Feet.
Fine yellowish micaceous sand, passing down into rubbly and sandy Malmstone	8
Buff-coloured Malmstone, in blocks, with fossils	10
Greenish sandy micaceous clay, full of water	2 to 3
Dark-grey (nearly black) clay, seen for about	10

Thence the outcrop runs northward through woodland to Woodhouse Farm, where there is a pond, and a spring which presumably rises from the Malmstone. This is below the contour of 500 feet, and there are other strong springs in Horningsham to the eastward, which are likewise below that level. Yet the ridge above

Horningsham Plantation rises to 749 feet, without any trace of the Chalk being found, though we have specially looked for it; the soil on the top of the ridge is sandy with fragments of chert. Thus, even if the actual base of the Malmstone is not below the contour of 500 feet, there seems to be 250 feet of Upper Greensand here, which is a much greater thickness than can be inferred to exist elsewhere in this part of Wiltshire.

Fossils from the Lower Sands of the Selbornian.

	Glauconitic sand.	Malmstone.	Gault.
Ammonites auritus, Sow.	...	*	
A. rostratus, Sow.	...	*	
A. splendens, Sow.	...	...	*
A. denarius, Sow.	...	...	*
Exogyra conica, Sow.	*	*	
Ostrea canaliculata, Sow.	...	*	
O. vesicularis, Sow.	...	*	
O. vesiculosa, Sow.	*		
Pecten Puzosianus, d'Orb.	*	*	
P. orbicularis, Sow.	*	*	
Neithea quadricostata (d'Orb.).	*		
N. quinquecostata (Sow.)	...	*	
Plicatula (?) sp.	...	*	
Modiola reversa, Sow.	...	*	
Pleuromya mandibula (d'Orb.)	...	*	
P. (?) sp.	...	*	
Arca carinata, Sow.	...	*	
Terebratulina Martiniana (?), d'Orb.	*		

NOTE.—*Pecten asper* has been found, in the green sand with large blocks or doggers of calcareous sandstone, which comes in below the Chert-Beds.

V. EXPOSURES OF CHERT-BEDS AND CHLORITIC MARL.

Maiden Bradley. (Fig. 1, p. 101 & Pl. IV.)

The most important section of these beds is that at Maiden Bradley, a village which lies in a hollow or combe facing northward, with slopes of Chalk-Marl and Chalk rising to the west, south, and east of it. The quarry exposing the junction of the Chalk and Greensand is situated on the west side of the village, about ¼ mile north-west of the church. It was opened to obtain chert and stone for road-metal, but has not been worked much during the last few years, because of the increasing thickness of sand and marl which has to be removed as the face is cut back.

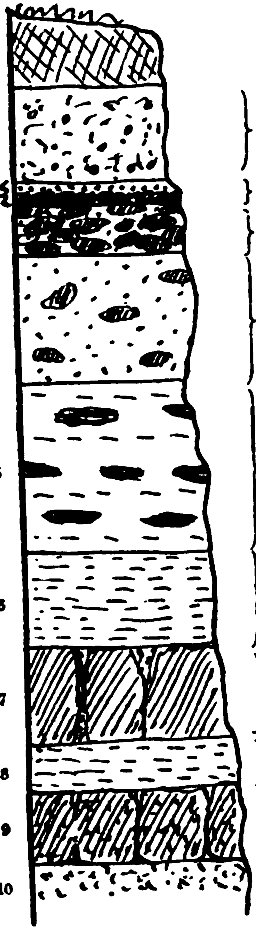
Fossils from this quarry have found their way into several public and private collections: in some they are labelled as coming from the junction of the Chalk and Greensand, in others they are referred to the Chloritic Marl. The real fact is that the quarry traverses both Chloritic Marl and Upper Greensand, and that both

yield fossils; but the greater number have come from a bed which lies at the junction of the two formations, and which on a first inspection it would be difficult to assign definitely to either.

It is only by a close observation of the section, and by careful collecting from each of the successive beds, that good reasons can be adduced for drawing the line of separation at one horizon rather than at another. We may admit that our first impressions were modified by later discoveries.

The section in this quarry is illustrated in fig. 1, below:—

Fig. 1.—*Section in Maiden Bradley Quarry.*



		Feet.	Inches.
	Surface-soil .... about	1	6
1	Chloritic Marl with scattered phosphates and phosphatised fossils, marly above, sandy below	2	0
2	Brownish glauconitic sand with a layer of phosphatic concretions and fossils at the base	0	6
3	Cornstones, or calcareous concretions with a brown phosphatic crust	1	0
4	Glauconitic sand with some scattered calcareous concretions	2	9
5	Fine greyish-white siliceous earth, with nodules of grey chert	3	6
6	Fine grey glauconitic sand, with large echinoderms and broken specimens of *Neithea*	2	0
7	Large blocks of chert, nearly continuous	2	0
8	Fine grey glauconitic sand	1	0
9	Hard, granular, spiculiferous sandstone	1	6
10	Granular sandstone and sand	1	0
		18	9

[Vertical scale: 4 feet = 1 inch.]

We now proceed to describe the characters and contents of each bed in detail.

(1) Chloritic Marl.—This stratum exhibits the usual appearance of Chloritic Marl in the Warminster district, where there is always a gradual passage from Chalk-Marl to a marly glauconitic sand. Only 2 feet of it are seen in the quarry; the white chalky matrix preponderates in bulk over the sandy constituents in the upper 6 inches; the central part is a greenish glauconitic marl; and in the lower 6 inches the material consists largely of quartz and glauconite-grains. Still, even in the lower part, there are small patches of very chalky matter, often lenticular in shape, and the mass is rendered coherent by the same material. The quartz-grains are mostly small, but large grains occur sporadically throughout.

Broken fragments of dark-brown phosphate are scattered through the whole of the 2 feet seen, with some phosphatic casts of fossils and a few phosphatic nodules. Fossils with calcareous shells, such as *Plicatula inflata*, are also common. These latter are clearly contemporaneous shells, while the phosphatic fossils may be derived, though few of them are rolled. The sponge *Stauronema Carteri*, so characteristic of Chloritic Marl, occurs throughout this bed.

Many of the phosphatic casts are black, but near the base many are brown, and some brown phosphatized shells occur like those in the brown layer below.

(2) The brown layer is only 5 or 6 inches thick, but is nevertheless a very important band, as it contains a great variety of fossils. The upper 3 inches is a greyish-brown glauconitic sand, containing small scattered lumps of phosphate and fossils; the lower 3 inches may be described as a conglomeratic layer of fossils and small phosphatized calcareous concretions.

There is no clear line of demarcation between this bed and the overlying Chloritic Marl, and the brownish tint is a mere coloration which has probably spread upward from the concretionary layer at the base. The sand is rather fine, and is mixed with a certain amount of chalky matter, which receives a green streak from the glauconite when the sand is cut with a knife. The concretions in the lower layer are mostly of a flattish oval shape, and have a dark brown crust which seems to be phosphatic but is probably also ferruginous. Their surface has a waterworn aspect, and is covered with small attached *Ostreæ, Plicatulæ, Serpulæ*, and bryozoa, showing that they lay for some time on the sea-floor before becoming embedded in the sand which now surrounds them. Some of them are between 3 and 4 inches long by 2 inches in width. Internally they are greyish, and of so fine a texture that even a lens does not disclose definite sand-grains; it shows, however, that the cementing matrix is crystalline calcite, and that there are a few minute scattered grains of glauconite.

The interstices between these concretions are filled with brownish sand, containing fossils in excellent preservation and all stained brown, so that they can generally be distinguished from those of the other beds in this quarry. In places the concretions, fossils, and

sand cohere together in lumps or masses. *Pecten orbicularis* occurs in scores, and *Catopygus columbarius*, *Holaster lævis*, *Rhynchonella grasiana*, and *Ammonites varians* are also very abundant. A list of the fossils obtained is tabulated on pp. 114–19.

(3) The Cornstones are a bed of hard calcareous concretions, closely packed together in a matrix of grey sand; these are covered with a dark-brown coating, and are locally called 'cornstones.' In shape they are mostly oval, and they run from 6 to 9 inches in length; they are covered with small *Serpulæ*, and occasionally one is pitted by the boring of a lithodomous mollusc. Internally they are greyish-white, and consist of the finest quartz-sand, without any visible glauconite, cemented by crystalline calcite into a hard compact stone. Between the stones a few fossils occur in the sand, such as *Catopygus columbarius*, *Discoidea subucula*, *Terebratula biplicata*, etc.; but they are not so abundant as in the layer above.

Bed 4 is a compact greenish-grey sand-rock or soft sandstone, with some calcareous matter. This bed encloses irregular lumps of whitish sandstone, which are dispersed through its whole thickness, and do not readily separate themselves from the sand. Notwithstanding this close association of matrix and concretions, the latter are not merely indurated portions of the former, for they consist entirely of fine white quartz-sand cemented by crystalline calcite; whereas the material of the bed itself contains many large grains of glauconite, and still larger scattered grains of quartz.

It is not easy to understand how lumps of one kind of sand could have become embedded in another kind of sand, unless they had been derived from some previously existing bed; but there is no trace of any such bed either here or in other parts of the district, and they do not present the aspect of derived stones. Moreover, the occurrence of such lumps of fine sandstone in coarser sand or sandstone is not limited to this district: it is a noticeable feature in the topmost bed of the Upper Greensand in Western Dorset and the adjacent parts of Somerset.[1] There the fine white sand sometimes separates itself in nodules, but more often appears simply in patches which merge on all sides into the surrounding coarser sand, and the whole mass is cemented by calcite into a hard rock which breaks independently through both finer and coarser portions.

There is no marked plane at the top of Bed 4. The sandy matrix which embeds the 'cornstones' passes down into the sand below, which for a few inches is stained by iron, and in this portion some of the same fossils occur as are found above. Fossils are not common, and become still scarcer in the lower part, *Rhynchonella grasiana* being the commonest. The base of Bed 4 is clearly marked, because there is a decided change in the character of the sediment forming the bed below.

[1] See Mem. Geol. Surv. 'Cretaceous Rocks of Britain' vol. i (1900) 'Gault & Upper Greensand of England' pp. 173, 177, etc.

(5) Very fine whitish siliceous earth or silt, too fine to be called a sand, containing large irregular masses of light-grey chert, which breaks into flattish slabs and angular pieces; these chert-masses are often 12 or 18 inches high, and are so distributed that in places the bed consists as much of chert as of soft silt. Crushed specimens of *Holaster lævis*, and broken fragments of *Pecten asper* and other shells, are common here. The thickness of this bed is about 3½ feet, but the silty portion is divisible into three bands which differ slightly in composition.

The upper band (12 inches thick) effervesces with acid, and is therefore somewhat calcareous. The residue breaks up with slight pressure, and, when washed, shows small quartz-grains to which adheres much dull white colloid silica; there are also many sponge-spicules, many small dark grains of glauconite, and some flakes of silvery mica: the finest part seems to consist chiefly of globular silica, mica, and sponge-spicules.

The next 12 or 13 inches may be described as a very fine, compact, silver-grey silt, composed of fine quartz-sand, colloid silica, and mica-flakes, with many spicules of Lithistid sponges and grains of yellowish-green glauconite; glauconite also occurs in the irregular hollows of the spicules.

The lowest part of the bed (18 inches) is a fine sand, very similar to that above it, but with less organic silica and more glauconite.

Bed 6 is a fine light-grey glauconitic sand, showing streaks or laminæ of slightly different tints, owing apparently to a varying proportion of glauconite-grains. It is divisible into two bands, the upper 8 inches being yellowish-grey, and consisting of minute even-sized quartz-grains with a fair sprinkling of glauconite-grains of nearly the same size as the quartz. This band weathers to a brownish-yellow, owing to the oxidation of the glauconite. It contains many broken shells, and some more or less perfect, among which the following have been identified:—

Ostrea canaliculata.	*Exogyra haliotoidea.*
Pecten Galliennei (?).	*Cardiaster fossarius.*
Neithea æquicostata.	*Cottaldia Benettiæ.*
—— *quadricostata.*	*Glyphocyphus radiatus.*
Plicatula sigillina.	Ossicle of starfishes.

The middle part of the bed (about 12 inches) is a fine greyish-white sand, with much colloid silica both scattered and in nests, and only a few small grains of glauconite. Below this are 6 inches of fine spiculiferous sand, consisting of a mass of broken sponge-spicules (chiefly Lithistidæ), the hollows and canals of which are filled with glauconite.

There are very few cherty concretions in these lower layers, and no fossils have been found in them, except siliceous sponges and sponge-stems and pieces of *Serpula* (*? annulata*).

(7) This is a bed of cherty material forming a continuous layer nearly 2 feet thick, but it breaks up into large irregular blocks. The outer portions are a greyish sponge-rock, the inner

parts being darker and more chalcedonic. Examination with a lens shows that it is full of sponge-spicules, which seem to have formed a matted mass of organic silica entangling some fine quartz-sand. Subsequently there was a partial solution of the colloid silica, some of it being redeposited in the central parts of the bed in a form which passed into chalcedony.

Bed 8 is a fine-grained, greyish, glauconitic spiculiferous silt, resembling the material of Bed 5. It consists largely of broken sponge-spicules and globular silica, this matrix appearing to the unassisted eye as a white floury matter; there is also much fine quartz-sand, many scattered grains of glauconite, and flakes of silvery mica. Tests of arenaceous foraminifera are common in this bed, but only a few fossils have been found, namely:—

Avicula gryphæoides.	*Serpula annulata (?).*
Pecten asper.	*Cardiaster fossarius* (crushed).
Ostrea canaliculata (?).	Siliceous sponges.

Bed 9 is a curious and interesting rock. Parts of it consist almost entirely of large broken sponge-spicules, cemented into a granular limestone by crystalline calcite; but the portions between these indurated lumps consist of glauconitic sand, both quartz and glauconite being in fairly large grains. With them, however, is much sponge-débris; therefore the rock may be called a calcified sponge-rock, and it shows that sponge-rock does not always give rise to chert.

Bed 10 is a hard calcareous and spiculiferous sandstone with a granular texture. It is the lowest bed actually quarried, but a small excavation made below it showed a few inches of greenish-grey sand enclosing small lumps of cherty stone.

Mr. Holbrook, of Maiden Bradley, who has worked in several of the quarries and has assisted in sinking wells in the village, informs us that beds containing flinty cherts occur to a depth of at least 12 feet below the bed of sandstone (No. 10); and further, that they include two beds of hard sandstone, formerly quarried for building-stone, of which the church and the older houses in the village have been built. Mr. Holbrook has given us the following as the general succession below the floor of the existing quarry at Maiden-Bradley:

	Feet.	Inches.
Hard sandstone with shells [*Neithea quadricostata*]	2	0
Layer of green sand	0	9
Sand with lumps of 'ruckly' flint [chert]	4	3
Very hard sandstone	1	3
Sand with 'ruckly' flints	4	0
Hard sandstone with shells	0	9
Green sand	10	0
Hard sandstone-rock	2	0
Sand, proved for	30	0

This would make the total thickness of beds containing chert about 24 feet. Part of the foregoing succession is confirmed by the section next to be described.

Baycliff Quarry.

The next good section is furnished by a quarry east of Baycliff Farm and rather more than a mile north-east of Maiden Bradley. This quarry is in a field on the north side of the main road, and the outcrop of the Chloritic Marl runs through the fields on the south side of the road, so that the section commences a few feet below the top of the Greensand. The following beds were exposed in 1900:—

		Feet.	Inches.
	Surface-soil, with large quartz-grains and many angular pieces of chert	1	6
A.	Light buff-coloured marly silt, enclosing lumps of grey chert which break into angular pieces	1	2
B.	Continuous layer of light-grey cherty stone	0	6
C.	Fine buff-coloured marly silt, with scattered grains of glauconite	2	0
D.	Hard grey spiculiferous sandstone	0	6
E.	Greenish-grey glauconitic sand, fine, soft, and laminated; with small irregular spongiform concretions	1	4
F.	Large lenticular masses of grey glauconitic and spiculiferous sandstone	2	0
	Irregular seam of yellowish sand and granular sandstone	0	8
G.	Rough granular calcareous and spiculiferous sandstone	1	3
H.	Greenish-grey glauconitic sand, enclosing large irregular masses of chert and cherty stone	3	0
I.	Greyish-white marly silt	1	2
J.	Hard grey granular calcareous sandstone, much like G	1	6
		16	7

The large quartz-grains in the soil have doubtless come from the disintegration of the sand below the Cornstones.

Bed A, which underlies the soil at this place, is a light buff-coloured, slightly calcareous silt or sandy marl. It effervesces when touched with acid, but is essentially a mixture of very fine sand and sponge-spicules with a little mica. It encloses lumps of chert, some of which are whitish throughout; others have a flinty core of solid grey or brown chalcedonic chert; they are scattered through the bed, but do not exceed 6 inches in diameter. This bed we identify with the lower part of Bed 5 at Maiden Bradley.

Bed C resembles A, but contains a larger proportion of small grains of glauconite. It encloses some small concretions of imperfect whitish chert, and the following fossils have been found in it:—

Cardiaster fossarius.	*Pecten orbicularis.*
Discoidea subucula.	*P. asper* (small and broken).
Epiaster Lorioli.	*Rhynchonella grasiana.*
Holaster lævis.	*Serpula* sp.

This bed appears to correspond with No. 6 of the Maiden-Bradley section.

The underlying bed (D) seems to represent No. 7 of that section.

It is a hard, greyish, siliceous cherty stone, full of sponge-spicules, but only 6 inches thick.

Bed E is a greenish-grey glauconitic sand, consisting largely of even-sized grains of quartz with many of glauconite, some of which are light green. At its base occur occasional lenticular layers of white floury silt, similar to the material in No. 8 of the Maiden-Bradley section, and in these many sponges are to be found: among them species of *Chenendopora*, *Doryderma*, *Nematinion*, *Pachypoterion*, and *Siphonia* have been identified for us by Dr. G. J. Hinde, F.R.S.

Bed F consists of two parts: (1) an upper course made up of large blocks of compact glauconitic sandstone in lenticular masses, but forming a nearly continuous course about 2 feet thick; and (2) a lower layer of yellowish sand which in places is concreted into granular spiculiferous sandstone. This band is noteworthy as having yielded several species of crustacea, and is probably the bed from which Baker, the fossil-collector of Warminster, obtained most of his crabs. The upper part has yielded *Necrocarcinus tricarinatus* and *N. glaber*, the latter being the new species described by Dr. Henry Woodward in 1898[1]: the lower part contains *N. glaber* and *N. Bechei*. *Pecten asper*, *P. orbicularis*, *Neithea æquicostata*, *Lima semiornata*, *L. semisulcata*, *Ostrea vesicularis*, and *O. vesiculosa* have been found in these two beds, which seem to represent the lowest horizons exposed at Maiden Bradley.

Bed G is a calcareous sandstone, consisting of quartz-grains, fragments of the large spicules of Lithistid sponges, and glauconite-grains, all cemented more or less firmly by crystalline calcite into a rock which is harder than any of the overlying beds. The only fossils obtained from it are *Lima semisulcata* and *Neithea æquicostata*.

Bed H is a compact grey glauconitic sand, effervescing freely with acid, so that it must contain much calcareous matter. When a portion is washed and placed under the microscope, it is seen to consist largely of small well-rounded grains of quartz-sand; grains of dark green glauconite are also abundant, with a few which are greenish-yellow; and there are many dull white bodies which seem to be foraminifera. Flakes of silvery mica also occur. This sand, as seen in the quarry, encloses many large irregular lumps or blocks of cherty stone, some of which weigh from 2 to 3 cwt. Most of these have centres of brown or black chalcedonic chert, and it is these cherts that make the best road-metal.

Broken pieces of *Pecten asper* are common in this bed, but the only other fossil found is a *Serpula*.

Bed I is a greyish-white marly silt, very like Beds A & C,

[1] Geol. Mag. 1898, p. 302.

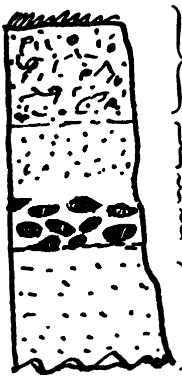
the components being chiefly minute quartz-grains, broken sponge-spicules, and globular silica, with a scattering of very small grains of glauconite and of broken glauconitic rods.

Rye Hill Farm. (Fig 2.)

We come next to the exposure near Rye Hill Farm, which is about 3 miles east-north-east of Maiden Bradley. This exposure was mentioned by one of us when discussing the Warminster fauna in 1896,[1] and was more fully described in a recent memoir of the Geological Survey.[2] It is important because it includes the junction of the sands with the Chloritic Marl; but it is unfortunately very small, consisting only of two holes from which sand has been dug for use on the farm.

These two pits supplement one another: one showing a marly sand with scattered brown phosphates, passing down into light green sand without phosphates; the other showing the same green sand passing into sand which contains many concretions like the Cornstones of Maiden Bradley, with sand again below. The second hole, however, has been dug in such a manner that it is not easy to measure the vertical thickness of the beds exposed; we therefore decided to have the other pit dug deeper, so as to get a clear vertical section. This was done in September 1900, with the result that the account previously published was found to require some modification. The thickness of the fossiliferous sand was found to be less than had been supposed, and the freshly-cut section was much more easily and satisfactorily correlated with that at Maiden Bradley. The succession is illustrated in fig. 2, below:—

Fig. 2.—*Section at Rye Hill Farm.*



		Feet.	Inches.
1	Chloritic Marl.—Sandy glauconitic marl, with phosphatic lumps and phosphatized fossils	2	0
2	Greenish-grey glauconitic sand, with many fossils but without phosphates; mostly soft, but with some roundish concreted lumps of sand	1	2
3	Soft yellowish-brown sand, with a few hard concreted lumps and many fossils	0	5
4	Greenish sand, with many oval calcareous concretions (Cornstones) and some fossils... from 6 inches to		9
5	Soft greenish-grey sand, with scattered calcareous concretions; few fossils	2	3
		6	7

[Vertical scale: 1 inch = 4 feet.]

[1] A. J. Jukes-Browne, Geol. Mag. 1896, p. 261.

[2] Mem. Geol. Surv. 'Cretaceous Rocks of Britain' vol. i (1900) 'Gault & Upper Greensand of England' p. 240.

Of these beds, No. 1 is similar to the lower sandy part of the Chloritic Marl with *Stauronema Carteri* at Maiden Bradley, but is rather less tough, owing probably to its occurrence at the surface and consequently its more decomposed and decalcified condition. It passes down into the still less calcareous sand below.

No. 2 is a sharp greenish sand containing quartz-grains of various sizes, some very small, some large, just as in the bed above. Here and there the sand is concreted into hard lumps, but no derived phosphatic nodules occur in it. Casts of *Ammonites varians* in a pale yellow calcareous material occur plentifully; they are often so decomposed as to fall to pieces, but if got out carefully they harden greatly in drying. Brachiopods are abundant, especially *Rhynchonella grasiana* and *Rh. dimidiata*, with *Terebratula biplicata* and *T. arcuata*. *Terebratella pectita* occurs as well, and *Catopygus columbarius* is common. This bed has hitherto been regarded as the highest part of the Upper Greensand, but it does not seem to correspond exactly with any particular layer at Maiden Bradley.

No. 3 we do not hesitate to regard as the equivalent of the brown sand and nodule-bed at Maiden Bradley. There is a sudden transition between this and the bed above, but it is due rather to coloration than to change in lithological character. It forms a layer of yellowish-brown sand, which contrasts with the greenish-grey sands above and below; its thickness varies from 4 to 6 inches, and it contains at intervals lumps of sand concreted by ferruginous matter, with which there are a few phosphates, but there is no layer of phosphatic concretions as at Maiden Bradley. Fossils, however, are more plentiful than in the sand above, and include most of the species common at Maiden Bradley: *Catopygus columbarius* is very abundant; the ammonites are chiefly *Ammonites varians* in a brownish calcareous phosphate; *Pecten asper* is common; and bryozoa are also plentiful.

(4) The brownish sand passes down into a greenish sand, in which are numerous calcareous concretions like the Cornstones of Maiden Bradley, only they are yellowish outside and not phosphatized. These cornstones are scattered thickly through 6 to 10 inches of sand; but they lie at various angles, and some of them have their longer axis nearly vertical. Many bear small attached oysters, so that they seem to have been indurated before they were brought into their present position, and yet they show no signs of long exposure or rolling. Some fossils occur in between the cornstones, such as *Pecten asper* and *Spondylus striatus*; *Terebratulæ* and *Rhynchonella grasiana* are found in great abundance; *Catopygus columbarius* is not uncommon, but *Terebratella pectita* is rare.

(5) The transition from the Cornstones to the sand below is sudden, and there is an equally sudden decrease in the abundance

of fossils. This bed is exactly like the sand which occupies the same position at Maiden Bradley, except that it is perhaps slightly finer in grain, consisting principally of small and fairly even-sized quartz-grains with a scattering of much larger grains; the grains of glauconite are dark green and of irregular shape. The grains of quartz appear to be rather less worn than those in the sand above the Cornstones. Hard whitish calcareous concretions occur in this sand, precisely as at Maiden Bradley.

Dead-Maid Quarry, Mere. (Fig. 3, p. 111 & Pl. V.)

The next exposure to which we shall call attention is a large quarry at a spot called the 'Dead Maid' on the north side of the main road, about ½ mile west of Mere and 4 miles south of Maiden Bradley. This has been largely worked for building-stone and cherts during the last few years, and exhibits the junction of the Chalk and Upper Greensand very clearly; but the details differ somewhat from those of Maiden Bradley and Rye Hill. The beds are seen to be inclined at an angle of about 5° to the eastward, and Pl. V is reproduced from a photograph of this quarry taken by one of us (J. S.) in 1899. The succession of beds at the eastern end of this quarry is illustrated in fig. 3, p. 111.

The hard Chalk-Marl (No. 2) splits into small flattish brick-shaped pieces, is light grey, and contains scattered grains of glauconite, which become rapidly more numerous towards the base. Fossils are not numerous, but *Pecten Beaveri*, *Lima aspera*, *Rhynchonella grasiana*, and a few others were found. It does not contain any phosphates.

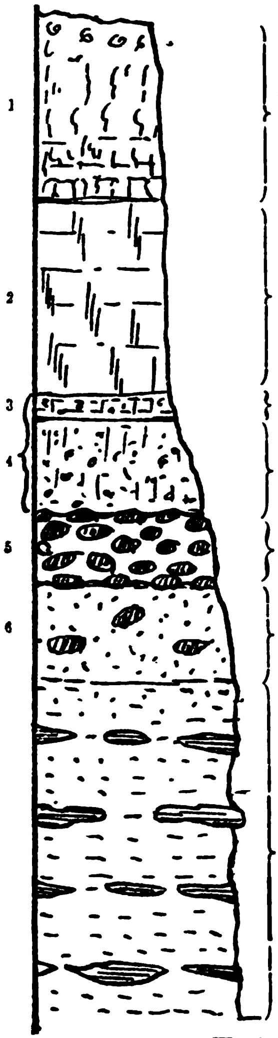
The layer below (No. 3) is rather less hard than the beds above and beneath it, but is in other respects a passage-bed. It is a compact glauconitic and sandy marl, mottled with bluish-grey streaks. It contains a few large grains of quartz.

The next bed (No. 4) is a hard massive glauconitic marl, or rather marlstone, including much quartz-sand, and containing many phosphatic nodules both large and small. Fossils are abundant throughout, and include *Ammonites varians*, *A. Coupei*, *A. Mantelli*, and *Turrilites Bergeri*. This is the Chloritic Marl. Its base is a clearly marked plane, and there is nothing to correspond exactly with the brown sand and nodule-bed of Maiden Bradley, unless it be the phosphate-crust, which in places coats the top of the underlying bed.

No. 5 is the most remarkable bed in the quarry, although it is only from 12 to 18 inches thick. In general colour and composition it resembles Bed 4, but contains a larger quantity of sand (quartz and glauconite) with less of the chalky matrix. The material has the hardness and consistency of good mortar; in it

are embedded many brown-coated stones like the Cornstones of Maiden Bradley, and like them varying in length from $1\frac{1}{2}$ or 2 inches across to such as are 4 or 5 inches long. Besides these many phosphatic nodules and phosphatic casts of fossils occur, and in places small patches of a more sandy material like that of the bed below, so that the bed is crowded with inclusions.

Fig. 3.—*Section at Dead-Maid Quarry, Mere.*



		Feet.
	Vegetable soil	½
1	Pale yellow chalky earth, apparently a wash of Chalk-debris filling a hollow	4
2	Soft Chalk-Marl, graduating down into hard rocky Chalk-Marl	4
3	Sandy glauconitic marl, with a few phosphatic fragments	⅓
4	Hard glauconitic marl, with many fossils and phosphatic nodules at the base	2
5	'Popple-bed,' brownish calcareous sand containing many hard stony concretions	1 to $1\frac{1}{2}$
6	Hard calcareous glauconitic sandstone, with some hard stony concretions; of irregular thickness, varying from	1 to 2
	Fine sand, with irregular masses of chert	6
		About 20

[Vertical scale: 1 inch = 4 feet.]

The stones are called popples by the workmen, and the bed is known as the popple-bed. Their external surface is rather rough, but rounded and apparently waterworn, and to it are attached many small *Serpulæ*, bryozoa, and other adherent organisms. When one is broken, it is seen that the external brown coating is thin, and is ferruginous though probably phosphatic as well; beneath it for a short distance the stone is rotted and stained yellowish-brown, but the rest of the popple consists of a very hard and compact calcareous sandstone, being really a fine-grained sand cemented by crystalline calcite. It contains minute scattered grains of glauconite, but these are only visible with a lens, whereas those in the surrounding rock are plainly visible to the eye and some are rather large.

Further, one of the stones that we extracted was penetrated by the boring of some lithodomous mollusc. The cylindrical hole was more than 1 inch deep, and was filled with the enclosing rock-material, which exhibits a marked contrast to that of the pebble. There can be no doubt that the stones have been washed out of some previously-formed deposit, and had been calcified and indurated before their inclusion in this bed. Many of the fossils in this bed, even the gasteropoda, retain their shells. (See List, pp. 114–19.)

Early in 1899, part of a fossil tree was found in this bed lying almost horizontally. According to the workmen, it was nearly 20 feet long, and the thickest end was about 15 inches in diameter; while the crushed top-branches covered an area of about 9 feet. It lay in a direction from north-north-east to south-south-west. Mr. A. C. Seward, F.R.S., has examined a fragment, and finds it to be coniferous wood.

(6) The base of Bed 5 rests upon an irregular surface of the underlying bed, but the latter does not differ very greatly in mineral composition. It exhibits, however, a maximum of sand with a minimum of chalky matrix, and so little chalky material occurs between the grains that what there is may possibly have been carried down mechanically from above. In this bed large grains of quartz are more abundant, and many of the glauconite-grains are also of considerable size.

Lumps or concretions of hard siliceous stone are scattered through this bed at irregular intervals. They vary in length from 3 to 18 inches and in diameter from 3 to 9 inches, but rarely exceed 5 inches across. They consist of fine sand cemented by crystalline calcite, and are similar to the central parts of the stones in the popple-bed, except that they have a lighter colour and a fresher appearance. Although these concretions appear to be *in situ*, they are not calcified portions of the surrounding sand, being of much finer grain and containing but little glauconite.

Fossils are so rare in this bed that we have not succeeded in finding any.

Bed 7 consists of fine-grained sand, with layers of calcareous sandstone and lenticular lumps of chert. The sand is principally

made up of quartz-grains, with a few scattered grains of glauconite and some calcareous particles which effervesce when it is treated with acid. At this end of the quarry only 5 or 6 feet of the sand is usually exposed, but it has been dug to a depth of 9 or 10 feet more without showing any marked change.

The beds above described rise westward, the higher strata gradually disappearing, till at the western end of the quarry the section seen is:—

	Feet
Surface-soil	¾
Rubble of 'popplestones' and phosphatic nodules embedded in sand	4
Fine-grained sands, with layers of chert and of calcareous sandstone, seen for	17
	21¾

The most remarkable feature in this section is undoubtedly the curious irregular bed which encloses the 'popplestones' and the marked break which occurs at its base. Equally curious is the absence of any bed to correspond with the sand, which, at Maiden Bradley and Rye Hill, intervenes between the Cornstones and the Chloritic Marl. It would appear that the sand with 'popplestones' here takes the place of the Cornstones and the overlying sand which is so rich in fossils farther north, for very many of the same species occur among the 'popplestones.' At any rate this bed seems to form a natural base to the Chloritic Marl, while the sand below it seems to fall more naturally into the underlying Upper Greensand.

Manor Farm, Mere.

There is one other exposure near Mere which is worthy of mention, because it suggests the existence of a flexure of the beds at this locality, and the possibility of a small inlier of the beds at the junction of Chalk and Upper Greensand to the north of Mere. A small pit has been opened in the field west of Manor Farm, and about ½ mile north-north-east of Dead-Maid Quarry; the hard Chloritic Marl is here close to the surface, and has been quarried for use as a rough building-stone, but the section has not been carried through it into the 'popplestone'-bed. There is no appreciable dip, and near the opening is a watercourse (dry in summer) running south-eastward to Mere. In this watercourse are stones like those which occur in the sand below the 'popplestones'; but at the 'Wellhead' spring north of Mere there is Chalk-Marl down to the spring-level.

It will be remembered that in Dead-Maid Quarry the beds are dipping eastward at an angle of about 5°; this, if continued, should carry the Chloritic Marl well below Mere. Probably the dip is really south-easterly; but even so, as the level of the surface at Dead Maid is about 370 feet and that at the other pit is about 380, the Chloritic Marl could hardly be at the surface at the latter place, unless it was brought up by a local anticlinal flexure. The

direction of the intervening ridge (Long Hill) is very suggestive of its coincidence with a syncline, and it is only natural to expect that the valley on the other side coincides with an anticline, the flexures being parallel one to the other and their axes being parallel to the line of outcrop on the west.

VI. List of Fossils from the Chert-Beds and Junction-Beds.

A list of the few fossils found in the lower part of the Upper Greensand has been given on p. 100.

The following list includes only those which have been actually found by Mr. Scanes, and obtained from the open exposures at Maiden Bradley, Baycliff, Rye Hill, and Mere. Those found at the first two localities are indicated by the letter *b*; those at the third by the letter *r*; and those at the fourth by the letter *m*.

All the mollusca, brachiopoda, and echinodermata have been examined and named by Mr. Jukes-Browne; but for the identification of the sponges we are indebted to Dr. G. J. Hinde, F.R.S., and for the names of some of the bryozoa to Prof. J. W. Gregory, D.Sc., F.G.S.

With regard to the fossils quoted in the second column, it should be mentioned that 80 per cent. of them have only been found at the very top of the bed immediately below the Cornstones at Maiden Bradley, and that none have been found in this bed at Rye Hill nor at Mere. The ammonites in this bed only seem to occur just below the Cornstones.

The fourth column includes fossils from the brown sand and phosphatic bed at Maiden Bradley (*b*), and from the equivalent brown and grey sand at Rye Hill (*r*).

	Chert-Beds.	Sand above Cherts.	Cornstones and Popple-Bed.	Phosphate-Bed and Rye Hill Sand.	Chloritic Marl.
Vertebrata.	I	II	III	IV	V
Ichthyosaurus campylodon? (tooth)	...	*b*	*b*	*b*	
Lamna appendiculata, Ag.	...	*b*	*b*	*b*	*b*
Oxyrhina sp. (tooth)	...	...	*b*		
Pycnodont-teeth	...	*b*	...	...	*b*
Cephalopoda.					
Ammonites complanatus, Sow.	...	...	*b*	*b*	
A. falcatus, Mant.	...	*b*	*b*	*b, r*	*b*
A. falcatus var. *curvatus*, Mant.	...	...	*b*	*b, r*	*b*
A. Mantelli, Sow.	...	...	*b, m*	*b, r*	*b, m*

LIST OF FOSSILS (*continued*).

	Chert-Beds.	Sand above Cherts.	Cornstones and Popple-Bed.	Phosphate-Bed and Rye Hill Sand.	Chloritic Marl.
	I	II	III	IV	V
Ammonites navicularis, Mant.	...	*b*	*b*, *m*	*b*	*b*, *m*
A. planulatus, Sow.	...	...	...	*b*	
A. varians, Sow.	*b* (one)	*b*	*b*, *r*, *m*	*b*, *r*	*b*, *r*, *m*
A. varians var. *Coupei*, Brongn.	...	*b*	*b*, *m*	*b*, *r*	*b*, *m*
Anisoceras sp.	...	...	...	...	*b*
Baculites baculoides, Mant.	...	...	...	*b*	*b*
Hamites, sp. 1	...	*b*	...	*b*	*m*
H. sp. 2	...	...	...	*b*	
Scaphites æqualis, Sow.	...	...	*b*	*b*	*b*, *m*
Turrilites Bergeri, Brongn.	...	...	...	*b*	*b*
T. elegans (?) P. & R.	...	...	...	*b*	*b*
T. Morrisi, Sharpe	...	...	...	*b*, *r*	*b*
T. tuberculatus, Sow.	...	...	*m*	*b*	*b*
T. Wiestii, Sharpe	...	...	*b*	*b*	*b*
T. sp. (oblique)	...	...	*b*		
T. sp. nov. (?)	...	...	*m*		
Belemnites attenuatus (?) Sow.	*b*	...	...	*b*	
Nautilus cf. *arcuatus*, Desh.	...	...	...	*b*	
N. Deslongchampsianus, d'Orb.	...	*b*	*b*	*b*	
N. elegans, Sow.	...	...	...	...	*b*, *m*
N. elegantoides (?)	...	...	...	*b*	
N. expansus, Sow.	...	...	*m*	*b*	*b*, *m*
N. Fittoni, Sow.	...	...	...	*b*	*b*
N. lævigatus, Sow.	...	...	...	*b*	*b*
N. Largilliertianus, d'Orb.	...	...	...	*b*	
N. semiundatus (?) Foord	...	...	*b*		
GASTEROPODA.					
Actæon elongatus, Sow.	...	...	...	*b*	*b*
Aporrhais Mantelli, Gard.	...	...	*m*	*b*	*b*
A. sp. nov. (?)	...	...	...	*b*	
Avellana cassis, d'Orb.	...	...	*m*	*b*, *r*	*b*, *r*, *m*
Cerithium sp. (casts and moulds)	...	...	...	*b*	*b*
Columbellina sp.	...	...	*m*		
Dentalium rothomagense, d'Orb.	...	*b*	*b*	*b*	*b*, *m*
Emarginula Greslyi (?) P. & C.	...	...	...	...	*b*
E. sp.	...	...	...	...	*b*
Fusus sp. (casts)	...	...	*m*	*b*	
Littorina (?) or *Scalaria*	...	...	...	...	*b*
Natica Gentii (?) Sow.	...	...	...	*b*	*b*
Pleurotomaria Brongniartina, d'Orb.	...	...	...	*b*	*b*
Pl. Gallienei (?) d'Orb.	...	...	...	...	*m*
Pl. perspectiva, Mant.	...	...	*b*, *m*	*b*, *r*	*b*, *m ?*
Pl. sp. 1 (tall)	...	...	...	*b*	
Pl. sp. 2	...	...	...	...	*m*
Pl. sp. 3	...	...	...	*m*	
Pl. sp. 4	...	...	...	...	*m*
Pterodonta (large sp.)	...	...	...	*b*	
Pt. (small sp.)	...	...	...	*b*	
Solarium bicarinatum, Fiessen	...	*b*	*b*, *m*	*b*	*b*

List of Fossils (*continued*).

	Chert-Beds.	Sand above Cherts.	Cornstones and Popple-Bed.	Phosphate-Bed and Rye Hill Sand.	Chloritic Marl.
	I	II	III	IV	V
Solarium dentatum, d'Orb.	...	b	b	b	b, m
S. ornatum, Sow.	...	...	...	b	b
S. triplex (?) P. & R.	...	...	...	...	b
S. sp. (with shell)	...	...	...	...	b
Tornatella elongata (see *Actæon*).					
Triton sp.	...	...	...	...	b
Trochus Cordieri (?) d'Arch.	...	...	...	b	
Tr. Goupilianus (?) d'Orb.	...	...	...	b	b
Tr. Roseti (?) d'Arch.	...	...	...	b	b
Turbo sp. (with cast of shell)	...	...	...	...	b
Lamellibranchia.					
Anatina sp. 1	...	...	...	b	
A. sp. 2	...	...	...	...	b
Anomia (?)	...	...	...	...	b
Arca Galliennei, d'Orb.	...	...	...	...	b
A. ligeriensis, d'Orb.	...	...	...	b	
A. Mailleana, d'Orb.	...	b	b	b, r	b, m
A. obesa, P. & R.	...	...	m	b	b, m
A. Passyana, d'Orb.	...	...	...	b, r	b, m ?
A. pholadiformis, d'Orb.	...	...	...	b	
Astarte sp.	...	...	...	b	
Avicula gryphæoides, Sow.	b	b	b	b	b
A. sp. (attached)	...	...	...	b	
Cardita Cottaldina, d'Orb.	...	...	...	...	b
C. sp. (casts)	...	...	...	b	b
Cardium alutaceum, Goldf.	...	...	b, m	b	
C. sp. (small casts)	...	b	b	b	b, m
Corbis rotundata (?) d'Orb.	...	...	...	b	b
Corimya (see *Thracia*).					
Cyprina quadrata, d'Orb.	...	...	b, m	b	b
C. sp.	b	b	...	b	
Cytherea sp.	...	b			
Exogyra conica, Sow.	b	...	b	b, r	b
E. conica, striated variety	b	b	b, m	b, r	b
E. haliotoidea, Sow.	...	...	...	b	
Gervillia solenoides, Defr.	...	...	...	b	
Hinnites sp.	...	...	b	b	
Inoceramus latus, d'Orb. (*non* Mant.)	...	?	...	b, r	b
I. striatus, Sow.	...	...	...	...	b
Lima aspera, Mant.	...	...	m	b	b, m
L. cenomanensis, d'Orb.	b				
L. globosa, Sow.	...	...	b	b, r	b, m
L. ornata (?) d'Orb.	...	...	...	b, r	
L. semiornata, d'Orb.	...	...	b	b, r	
L. semisulcata, Nilss.	b	b	m	b ?	
L. simplex (?) d'Orb.	...	...	...	r	
L. sp. nov. (sixteen ribs)	...	...	...	b	
L. sp. nov. (many ribs)	...	...	...	b	
Modiola Cottæ (see *Septifer lineatus*).					

List of Fossils (*continued*).

	Chert-Beds.	Sand above Cherts.	Cornstones and Popple-Bed.	Phosphate-Bed and Rye Hill Sand.	Chloritic Marl.
	I	II	III	IV	V
Ostrea canaliculata, Sow.	*b*	*b*	*b*	*b*, *r*	*b*
O. frons, Park.	...	...	*b*	*b*	*m*
O. Normanniana, d'Orb.	...	...	*m*	*b*, *r*	
O. vesicularis, Sow.	*b*	*b*	*b*, *m*	*b*, *r*	*b*, *m*
O. vesiculosa, Sow.	*b*	...	...	...	*m*
Nucula cf. *impressa* (cast)	...	...	...	*b*	
Nuculana sp. (cast)	...	...	...	*b*	
Pecten asper, Lam.	*b*	...	*b*, *r*	*b*, *r*	*b*
P. Beaveri, Sow.	...	...	...	...	*b*, *m*
P. elongatus, Lam. (= *crispus*, Goldf.)	...	...	...	*b*, *r*	*b*
P. elongatus, d'Orb.	...	...	...	*b*	
P. Galliennei, d'Orb.	*b*	...	...	*b*	
P. hispidus, Goldf.	*b*	...	*b*	*b*, *r*	
P. orbicularis, Sow.	*b*	*b*	*b*	*b*	*b*
P. Passyi, d'Arch.	...	*b*	...	*b*	*b*
P. Puzosianus (?) d'Orb.	*b*	*b*	*b*	*b*, *r*	*b*, *m*
P. subacutus, Lam.	...	...	...	*r*	
P. subinterstriatus, d'Arch.	*b*	...	*b*	*b*	*b*
P. sp. (close-set rounded ribs)	...	*b*	*b*		
P. sp. (with straight ribs)	*b*	...	*b*		
P. (Neithea) æquicostatus, d'Orb.	*b*	...	...	*b*	
P. (N.) cometa, d'Orb.	*b*	...	...	*b*	*b*
P. (N.) quadricostatus, Sow.	*b*	...	...	*r*	
P. (N.) quinquecostatus, Sow.	*b*	*b*	*b*, *r*	*b*, *r*	*b*
Pectunculus sublævis (?)	...	...	...	*b*	
Perna sp.	...	...	...	*b*	
Pholadomya decussata, Phil.	...	...	...	*b*	
Pleuromya plicata (d'Orb.)	...	...	...	*r*	*m*
Plicatula pectinoides, Sow.	...	...	...	*b*, *r*	*b*, *m*, *r*
Pl. pectinoides var. *inflata*, Sow.	...	...	*m*	*b*	*b*, *m*
Pl. sigillina, Woodw.	*b*	...	...	*b*	*b*
Radiolites Mortoni, Mant.	*b*				
Septifer lineatus (Sow.)	...	...	...	*b*	
Spondylus striatus, Sow.	...	...	*b*	*b*, *r*	*b*, *r*
Sp. sp.	...	...	...	*b*	
Teredo amphisbæna, Goldf.	...	...	...	*b*	
T. sp.	...	...	...	...	*b*
Thetis Sowerbyi, Rœm.	...	...	*b*	*b*	
Thracia carinifera, Sow.	...	...	...	*b*	*b*
Trigonia crenulifera (?) Lyc. (cast)	...	*b*	*b*	*b*	
Tr. scabricola (?) Lyc. (cast)	*b*				
Tr. Vicaryana, Lyc. (cast)	...	...	*b*, *m*	*b*	*b*, *m*
Unicardium ringmeriense, Mant.	...	...	*m*	*b*	*b*, *m*
Venus rothomagensis, d'Orb. (cast)	...	...	...	*b*	*m*
Brachiopoda.					
Lingula subovalis, Dav.	...	...	...	*r*	
Kingena lima, Defr.	...	*b*	*b*	*b*, *r*	*b*
Rhynchonella dimidiata, Sow.	...	...	*b*, *r*, *m*	*b*, *r*	*b*
Rh. dimidiata var. *convexa*, Sow.	...	...	*b*	*b*	*b*

List of Fossils (*continued*).

	Chert-Beds.	Sand above Cherts.	Cornstones and Popple-Bed.	Phosphate-Bed and Rye Hill Sand.	Chloritic Marl.
	I	II	III	IV	V
Rhynchonella dimidiata var. *Schlœnbachi*, Dav.	...	...	*b*	*b*	
Rh. grasiana, d'Orb.	...	*b*	*b, r*	*b, r*	*b, m*
Rh. Mantelliana, Sow.	...	...	*b, r*	*b*	*b*
Rh. Martini, Sow.	...	...	...	...	*b*
Terebratella pectita, Sow.	...	*b*	*b, r*	*b, r*	*b*
Terebratula arcuata, Rœm.	...	*b*	*b*	*b, r*	*b*
T. biplicata, Sow.	...	*b*	*b, m*	*b, r*	*m*
T. biplicata (flat variety)	...	...	*m*	*b*	
T. squamosa, Mant.	...	...	*b, r*	*b, r*	
Terebratulina striata, Wahl.	...	...	...	*b*	*b, m*
T. triangularis, Eth.	...	...	...	*b*	*b*
T. sp. (broad)	...	...	...	...	*b*
Terebrirostra lyra, Sow.	...	...	...	*b, r*	*b, m*
Bryozoa.					
Diastopora escharoides, Mich.	...	...	*b*	*b*	
Heteropora	...	...	*b*	*b*	
Membranipora (two species)	...	...	...	*b, r*	
Meliceritites semiclausa (Mich.)	...	...	...	*r*	
Micropora sp.	...	...	...	*b*	
Radiopora tuberculata	...	...	...	*b, r*	
Reptomultisparsa megalopora (Vine)	...	...	...	*b*	
Stomatopora granulata, Edw.	...	...	*b, m*	*b*	*b*
Spiropora micropora, Vine	...	...	*b*		
Crustacea.					
Necrocarcinus Bechei, Deslong.	*b*	...	...	*b*	
N. glaber, H. Woodw.	*b*				
N. tricarinatus, Bell	*b*				
Palæocorystes (?)	...	...	...	...	*b*
Phlyctisoma ? (claw of)	...	...	...	*b*	
Pollicipes Bronni, Rœm.	...	...	*b*	*b*	
Annelida.					
Serpula annulata (?) Sow.	*b*	*b*	...	*b, r*	
S. plexus, Sow.	...	...	...	*r*	
S. umbonata, Sow.	...	...	*b*	*b*	*b*
Echinodermata.					
Cardiaster fossarius, Benett	*b*	...	?		
C. suborbicularis (?)	...	...	...	*b*	
Catopygus columbarius, Lam.	...	*b*	*b, r, m*	*b, r*	*b, m* (base)
Cottaldia Benettiæ, Kœnig	*b*	...	*b*	*b, r*	
Discoidea subucula, Klein	*b*	*b*	*b, m*	*b, r*	*b, r, m*

LIST OF FOSSILS (*continued*).

	Chert-Beds.	Sand above Cherts.	Cornstones and Popple-Bed.	Phosphate-Bed and Rye Hill Sand.	Chloritic Marl.
	I	II	III	IV	V
Echinobrissus lacunosus, Goldf.	...	*b*	*b, r*	*b, r*	
Echinoconus castanea, Brongn.	...	...	*b*	*b*	*b, m*
Echinocyphus difficilis, Ag.	...	...	...	*b*	*b*
Echinospatangus Murchisoni, Mant.	*b*				
Epiaster Lorioli, Wright	*b*				
Glyphocyphus radiatus, Hœning	*b*	...	...	*r*	
Goniophorus lunulatus, Ag.	...	...	...	*b*	*b*
Hemiaster Morrisi, Forbes	...	...	...	...	*b*
Holaster lævis, Ag.	*b*	*b*	*b, r*	*b, r*	
H. obliquus (?) Wright	...	...	...	...	*b*
H. suborbicularis, Wright	...	...	...	*b*	
H. subglobosus var. *altus*, Ag.	...	...	...	...	*m*
H. trecensis, Leym.	...	...	...	...	*b*
Nymphaster latum ? (ossicles)	*b*	...	...	*b, r*	
Peltastes clathratus, Ag.	...	...	...	...	*b*
P. umbrella, Ag.	...	...	...	...	*b*
P. Wiltshirei, Wright	...	...	...	*r*	
Pseudodiadema Benettiæ, Forbes	...	*b*	*b*	*b*	
Ps. ornatum, Goldf.	*b*	...	...	*b ?*	
Ps. variolare, Ag.	*b*	...	...	*b*	
Salenia Austeni, Wright	...	...	...	...	*b, m*
S. petalifera, Desm.	...	...	...	*b*	
ACTINOZOA.					
Micrabacia coronula, Goldf.	...	...	...	*b*	*b*
Coral (? genus)	...	...	...	*b*	
SPONGIDA.					
Aphrocallistes sp.	...	...	...	...	*b*
Chenendopora callodictya (?) Zitt.	...	...	...	*b*	*b*
Ch. Michelini, Hinde	*b*				
Ch. sp.	*b*				
Doryderma Benettiæ, Hinde	*b*				
Elasmostoma consobrinum, d'Orb.	...	...	...	*b, r*	
Nematinion sp. (stem of)	*b*				
Pachypoterion sp.	*b*				
Parkeria (?) sp	*b*				
Plocoscyphia fenestrata, Smith	...	...	...	*b*	*b*
Pl. sp.	...	...	...	*b*	
Porosphæra urceolata, Phil.	...	...	...	*b, r*	*b*
P. globularis	*b*	...	...	...	*b*
P. sp.	...	...	*b, m*	*b*	*b*
Siphonia tulipa, Zitt.	*b*				
Stauronema Carteri, Sollas	...	...	...	...	*b*
Tremacystia Orbignyi, Hinde	...	*b*			

VII. Conclusions.

The sections described in the foregoing pages show that in this part of Wiltshire both the Selbornian and the Cenomanian stages are very fully represented. It is convenient to use these terms, because they denote definite divisions or stages in a palæontological scheme of classification; whereas the terms which have hitherto been in use in this country (namely, Gault, Upper Greensand, and Lower Chalk) denote merely local lithological facies of one or the other stage. The relations of the beds which constitute the Selbornian have been discussed elsewhere,[1] and it has also been shown that the Chloritic Marl (or sub-zone of *Stauronema Carteri*) belongs to the Cenomanian stage,[2] which in England has generally, but not always, a chalky facies.

In some districts, notably in Kent and Dorset, there is a marked plane of separation between the Selbornian and the Cenomanian stages, so that there is no difficulty in those counties in deciding which beds belong to each. Elsewhere, however, as in Southern Wiltshire and in the Isle of Wight, there is more difficulty because a set of passage-beds come into the sequence, which do not exist either in Kent or in Dorset.

These passage-beds have evidently been formed during an epoch of transition, when the physical conditions which had prevailed during the Selbornian age were being changed and those of the Cenomanian age were being ushered in. It was a time when parts of the sea-floor were swept by strong currents, for these passage-beds almost always exhibit clear evidence of current-action, such as uneven floors, piped surfaces, phosphatic concretions, and water-worn stones; while the absence of such passage-beds in Kent and Dorset is evidently due to the action of still stronger currents.

It is obvious that deposition may have been going on in one place while erosion was in progress not far away; and consequently it is improbable that a break or clear plane of demarcation, observable at one locality, should occur exactly on the same geological horizon as that seen at another locality.

In considering any single exposure, or those within a small area where fossils are abundant, the local evidence must of course be reviewed on its own merits. When, however, we come to consider the relations of one formation to another throughout a large area or region, such as the whole of Southern England, and have to decide on the most convenient plane of demarcation between them, then we are bound to take into account all the facts of the case, and the plane decided upon should be that which harmonizes best with all these facts, both stratigraphical and ontological. In other words, a line which seems convenient at one locality, where perhaps the succession is especially complete, may or may not be fittingly applicable to a

[1] Mem. Geol. Surv. 'Cretaceous Rocks of Britain' vol. i (1900) 'Gault & Upper Greensand of England' pp. 3, 30.

[2] Quart. Journ. Geol. Soc. vol. lii (1896) pp. 171, 172.

larger region. The point of these remarks will be seen in the sequel.

Let us first take the local succession which has been described, and endeavour to determine what horizon is suggested by the evidence as the most convenient plane of division between the Selbornian and the Cenomanian in this part of Wiltshire.

At Maiden Bradley the beds through which a passage takes place show no decided break of continuity, though they are appreciably distinct one from the other, and the upper surface of the Cornstone-Bed is a fairly well-marked plane. Still no one could decide, from a mere inspection of the section, which was the most natural plane of separation between the two formations; nor, as a matter of fact, is the evidence of the fossils very decisive on the point. It might be taken at the base of the Chloritic Marl, below which *Stauronema* does not occur, and to which a few other species seem to be confined, such as *Hemiaster Morrisii*, *Pecten Beaveri*, *Rhynchonella Martini*, *Salenia Austeni*, and *Holaster trecensis*. But all the characteristic ammonites of the Chloritic Marl are common in the nodule-bed below, and are not unfrequent among the Cornstones; while some of them occur also at the top of the sand which rests upon the Chert-Beds.

A large number of the fossils which occur in the nodule-bed (No. 2) do not occur below the Cornstone-Bed; but, since fossils are rare in the underlying sand, it may be that their absence is a mere local accident. On the other hand, nearly all the fossils which have been found in this sand range up into the Cornstones.

At Rye Hill there is a still more complete sequence, and the Chloritic Marl passes down into a sand which yields a large number of the fossils that have been catalogued as those of the Warminster Greensand. Some of the Chalk-Marl ammonites, namely, *Ammonites varians*, *A. Coupei*, *A. Mantelli*, and *A. navicularis*, occur in this sand: the first abundantly, the others more rarely; and we have no hesitation in regarding this sand, with the brownish layer at its base, as an expansion of the nodule-bed and brown sand of Maiden Bradley. The Cornstones and the sand below them have the same relations as at Maiden Bradley; there does not appear to be any kind of break, either above or below the Cornstones. Fossils are so rare, in the small area of the lower sand exposed, that the fauna associated with *Ammonites varians* does not actually set in till the upper third of the Cornstone-Bed is reached.

At Mere the base of the Chloritic Marl or *Stauronema*-bed is fairly well marked, and there is nothing to correspond with the nodule-bed of Maiden Bradley or with the upper fossiliferous part of the Rye Hill Sand. Nevertheless, there is no evidence of strong erosion, and the cephalopodan fauna of the Chloritic Marl descends into the Popplestone-Bed, which is the equivalent of the Cornstone-Bed of the other localities. Finally, the uneven base of the

Popplestone-Bed is a clear line of separation from the sand below, and the chief palæontological break coincides with this line; though, again, this may be due to the rarity of fossils in the sand below. Both here and at Maiden Bradley this sand contrasts markedly in lithological character with the fine silts of the underlying Chert-Beds.

We think that anyone who studies these sections by themselves will come to the conclusion that the most natural plane of division, so far as the local distribution of fossils is concerned, is at the base of the Cornstone-Bed. But he will be compelled to admit that a greater abundance of fossils in the sand below might oblige him to place the division a few feet lower down; and he must also admit that there is a certain change of fauna where *Stauronema Carteri* comes in.

The close affinity between the so-called 'Warminster fauna' and that of the Chloritic Marl was perceived by the late C. J. A. Meÿer so long ago as 1874,[1] when he expressed his belief that

'the fossiliferous portion of the so-called Upper Greensand of Warminster is, properly speaking, Chloritic Marl instead of Upper Greensand, as usually stated.'

The many points of connexion between the two faunas were admitted by one of us in 1896, who remarked that[2]

'if the Rye Hill Sand were only known as an outlying patch situated further west, and we had only the evidence of the fossils to guide us in determining its geologic age, it might have been regarded as a shallow-water deposit of the age of the Chalk-Marl, and the ammonites might have been appealed to as strong evidence in support of the contention.'

At the same time, this Rye Hill Sand was retained in the Upper Greensand, and distinguished from the true Chloritic Marl because the latter was found to lie above it. With this view Mr. Meÿer had previously signified his agreement in a joint note with the same writer.[3]

If the evidence adduced in the present paper obliged us to reconsider the above conclusion, and to regard the more fossiliferous part of the Rye Hill Sand as attached to the Chloritic Marl rather than to the Upper Greensand, it is evident that the fauna which has been recorded from that sand would have to be transferred from the Selbornian to the Cenomanian.

It is here that the considerations mentioned on p. 120 come in; and consequently we must make some reference to other localities, in order to see whether such a re-arrangement would not raise more difficulties than it would solve.

If we follow the beds from Southern Wiltshire into Northern Dorset, we find a large area where there is a clear plane of demarcation between the Greensand and the Chalk. The topmost bed of

[1] Quart. Journ. Geol. Soc. vol. xxx, p. 381.
[2] Jukes-Browne in Geol. Mag. 1896, p. 272.
[3] See Geol. Mag. 1894, p. 495.

the former contains a fauna comparable with that of the Cornstones and the Rye Hill Sand[1]; while the base of the latter is a glauconitic chalk which has a Chalk-Marl fauna, but does not contain *Stauronema*. Here, therefore, the sub-zone of *Stauronema* appears to be absent; and a fauna resembling that of Rye Hill and Maiden Bradley occurs in a bed which is inseparable from the Greensand, and strongly marked off from the Chalk. The same is the case both in Western and in Southern Dorset, many exposures occurring in both districts and displaying the same general features.

In the Isle of Wight the circumstances are different: the *Stauronema*-beds are well developed, and in most places have a nodule-bed at their base, which rests on a piped surface of laminated sand. This sand, however, does not contain many fossils, and, if comparable with anything at Maiden Bradley, it may be paralleled with the sand below the Cornstone-Bed. Here, therefore, on the contrary, we have no satisfactory base to the Lower Chalk, without including something that may correspond to the Rye Hill Sand.

In Northern Wiltshire, near Urchfont and Devizes, there is again a well-marked base to the *Stauronema*-zone, and an absence of any beds exactly comparable to the upper part of the Rye Hill Sand.

The evidence of these other localities is therefore conflicting, and it cannot be denied that the systematic geologist is here confronted with the horns of a dilemma: he must either exclude the Rye Hill fauna from the zone of *Ammonites varians*, although the cephalopoda of the Chalk-Marl are prominent members of it; or else he must include in that zone beds which are in some places separated by a strong physical and ontological break.

If the succession in Dorset and Northern Wiltshire were like that in Southern Wiltshire, we should have no hesitation in so dividing the two formations as to place the Rye Hill fauna in the Cenomanian or Lower Chalk stage, because that would seem a natural inference from the evidence which we have recorded in this paper. We feel, moreover, that such an arrangement would bring the Cenomanian of England more into line with the Cenomanian of French geologists, who insist upon including within it every bed that contains *Ammonites varians*.

It is consequently with some reluctance that we retain the arrangement that is at present accepted, and we wish it to be clearly understood that we do so only for the sake of convenience, and in spite of the evidence adduced in the foregoing pages. It is, in fact, one of those cases in which the palæontological is in conflict with the stratigraphical evidence. If the break in Dorset were not where we believe it to be, we could follow the lead of palæontology; but, in the present state of our knowledge, we prefer to take the stratigraphical line in Dorset as the least awkward of the two alternatives.

[1] See Proc. Dorset Nat. Hist. & Ant. Soc. vol. xvii (1896) p. 99, & Mem. Geol. Surv. 'Cretaceous Rocks of Britain' vol. i (1900) pp. 243 *et seqq.*

There is, however, a possible way out of the difficulty. The contemporaneous fauna of the top bed of the Upper Greensand in Dorset is certainly similar to that of the Rye Hill Sand and the phosphate-bed at Maiden Bradley; but though fossils are abundant therein, *Ammonites varians* is not common. Hence it is possible that this bed is really the equivalent of the sand below the Cornstones only, and that the gap in Dorset is represented in Wiltshire not only by the *Stauronema*-bed, but also by the Cornstones and the sand between them. If this be the case, the objection to the inclusion of the Cornstones and the fossiliferous part of the Rye Hill Sand in the zone of *Ammonites varians* would cease to exist. We propose to make further examination of the Dorset sections in order to satisfy ourselves on this point.

Meantime, both in order to emphasize the importance of the Rye Hill fauna, and to distinguish these beds from the rest of the Selbornian Sands, we propose to group these debatable beds as a distinct zone or sub-zone. For this the Echinid *Catopygus columbarius* will serve as an appropriate index, since it is especially abundant both at Rye Hill and Maiden Bradley as well as in Dorset, while it is rarely found in the Chloritic Marl above.

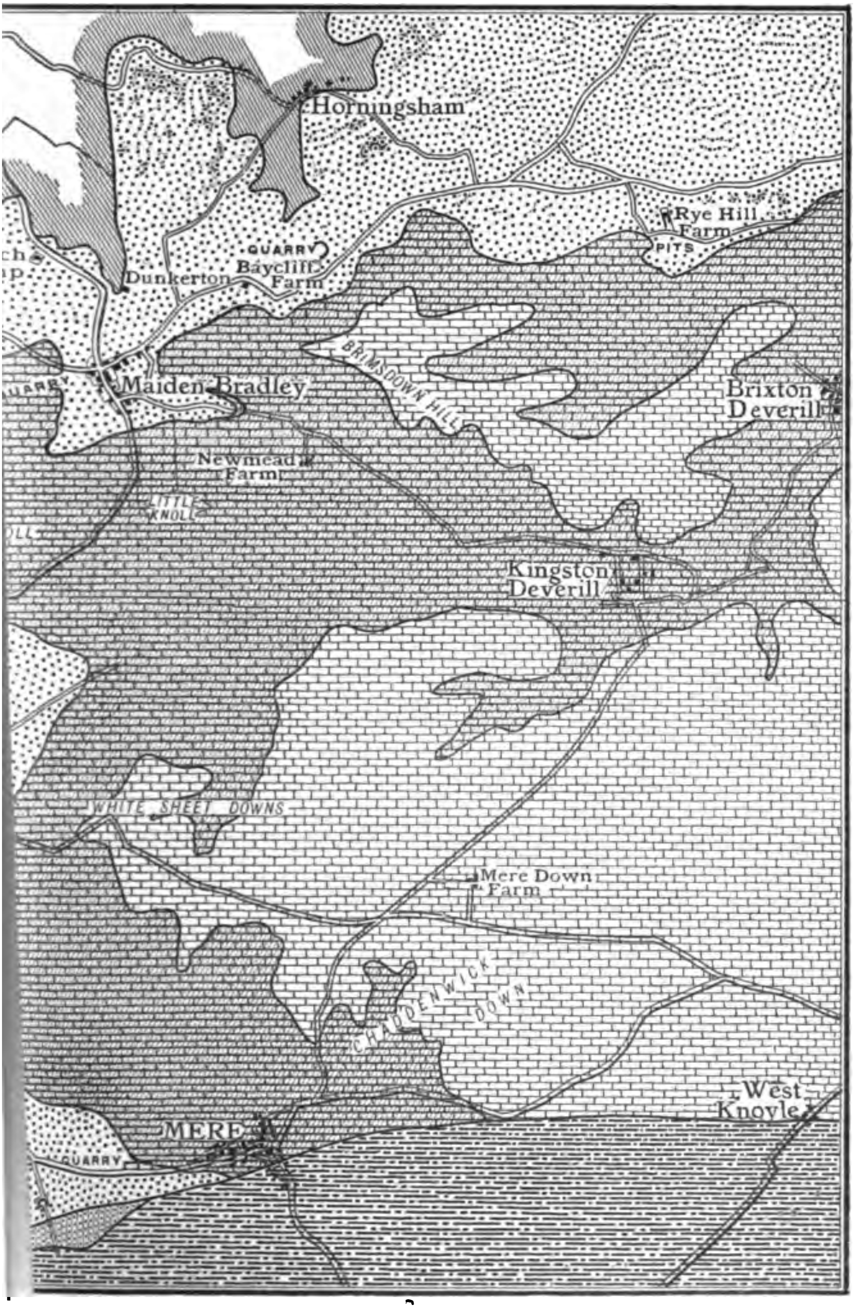
Where most complete, as at Rye Hill, this sub-zone consists of three distinct beds, which, in descending order, are:—

(3) Brownish sand, with many fossils, passing up into greenish-grey sand.
(2) A layer of calcareous concretions (the Cornstones).
(1) A greenish sand-rock, with calcareous concretions.

The recognition of such a zone or sub-zone of *Catopygus columbarius* will be of service, because it will not only indicate the existence of certain passage-beds in Southern Wiltshire, which form an important factor in the complete sequence, but it will also enable us to refer with greater precision to their correct horizon in the series such portions of a less complete succession as occur in other places. Thus we can say that, in Dorset, a part at least of the sub-zone of *Catopygus columbarius* is present, and it will be interesting to ascertain whether there are any traces of the former existence of this zone in the Isle of Wight.

The following is the sequence of beds which can be recognized at the junction of the Selbornian and Cenomanian, where the succession is complete:—

4. Chalk-Marl.
3. Sub-zone of *Stauronema Carteri*.
2. Sub-zone of *Catopygus columbarius*.
1. Chert-Beds.


Horningsham
Rye Hill
Farm
PITS
QUARRY
Baycliff
Farm
Dunkerton
Maiden Bradley
BRIMSDOWN HILL
Brixton
Deverill
Newmead
Farm
LITTLE
KNOLL
Kingston
Deverill
WHITE SHEET DOWNS
Mere Down
Farm
CHADDENWICK
DOWN
West
Knoyle
MERE
QUARRY

MAIDEN BRADLEY QUARRY (WILTSHIRE).

A = Chloritic Marl, with brown sand | C = Sand below the Cornstones.

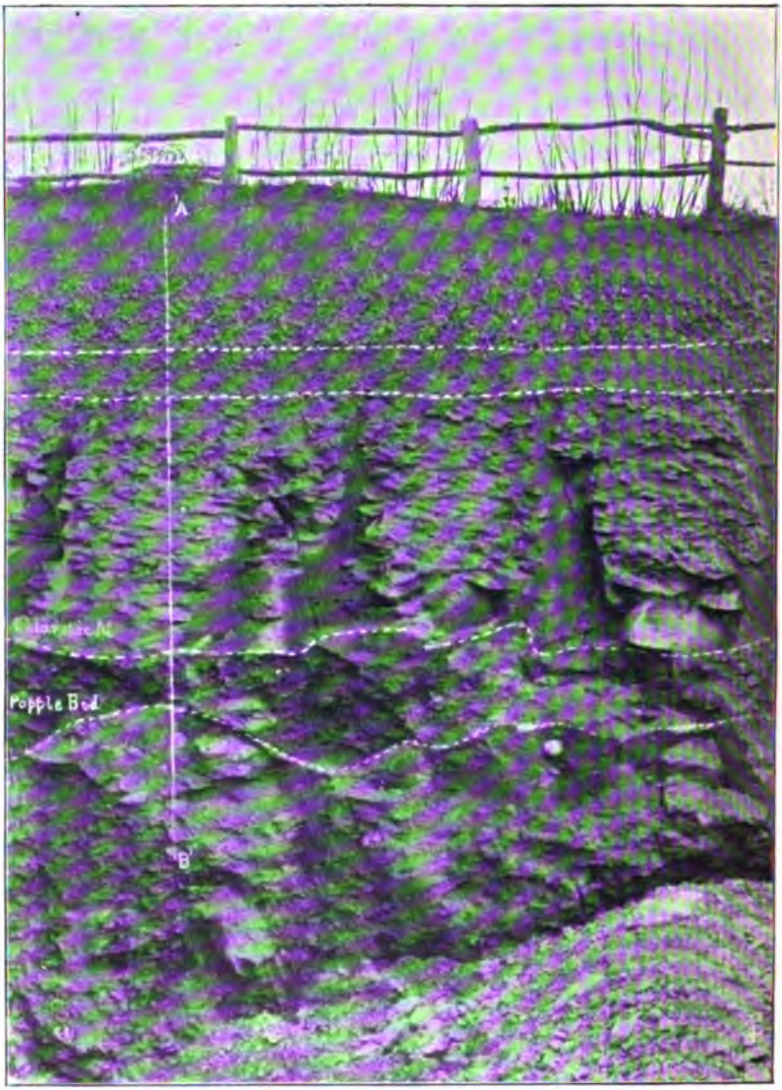
A

B

C

D

E



DEAD-MAID QUARRY, MERE (WILTSHIRE).

A = Chalky Clay; B = Hard Chalk Marl; C = Chloritic Marl; D = Popple Bed;
E = Bed C of Maiden Bradley (see Pl. IV).

[The vertical line A′ B′ indicates where the section was taken.]

EXPLANATION OF PLATES III–V.

Plate III.

Geological Map of the District of Mere and Maiden Bradley, on the scale of 1 inch to the mile.

Plate IV.

View of Maiden Bradley Quarry, showing the following succession:—
A = The Chloritic Marl, with the position of the nodule-bed represented by the uppermost stippled line.
B = The Cornstone-Bed.
C = The sand below the Cornstones.
D = The Chert-Beds, obscured at the base by fallen débris.

Plate V.

View of part of Dead-Maid Quarry near the eastern end, where the fossil tree-trunk was found, a portion of which is embedded in the Popple-Bed, a little to the right of the vertical white line. This line indicates the point where the section given on p. 111 was measured.

The lowest stippled line marks the uneven base of the Popple-Bed. The line denoting its summit rather exaggerates the actual unevenness, which may be partly due to lateral pressure affecting beds of different degrees of hardness.

Discussion.

Mr. Lamplugh remarked that one of the Authors had shown inconsistency in taking a lithological in preference to a palæontological division in this case, whereas in the parallel case of the zone of *Ammonites mammillaris* at the base of the Selbornian he had recently taken the opposite course. These constant difficulties in regard to the boundaries of formations showed how local most of such boundaries were, and how arbitrary and conventional they must necessarily be when applied over extended areas.

The Rev. H. H. Winwood and Mr. Whitaker also spoke.

9. BAJOCIAN *and* CONTIGUOUS DEPOSITS *in the* NORTH COTTESWOLDS: *The* MAIN HILL-MASS. By S. S. BUCKMAN, Esq., F.G.S. (Read December 5th, 1900.)

[PLATE VI—MAP.]

CONTENTS.

I. INTRODUCTION.

THIS paper is a continuation of two former communications published by the Society, namely, 'The Bajocian of the Mid-Cotteswolds,' Quart. Journ. Geol. Soc. vol. li (1895) p. 388, and 'Deposits of the Bajocian Age in the Northern Cotteswolds: The Cleeve Hill Plateau,' vol. liii (1897) p. 607. So far as the sequence of the strata themselves was concerned, the results arrived at in these two papers may be best expressed in Table I (p. 127).

What the Table indicates is this:—In a north-easterly traverse from Birdlip to Cleeve there are found, at Leckhampton Hill five distinct beds separating two strata which at Birdlip were in juxtaposition; and at Cleeve Hill, three more distinct beds separating two beds which at Leckhampton Hill were in juxtaposition, namely, the Upper *Trigonia*-grit and the Notgrove Freestone, and another distinct bed separating two other beds similarly placed at Leckhampton—the Snowshill Clay and the Upper Freestone. Consequently where nothing is intervening at Birdlip there are five beds inserted at Leckhampton Hill, and nine beds inserted at Cleeve Hill: that is, with regard to the five at Leckhampton, three additional at the top, and one more at the bottom.

TABLE I.—SEQUENCE OF STRATA.

Birdlip.	Leckhampton Hill.	Cleeve Hill.
		Upper *Trigonia*-grit.
	Upper *Trigonia*-grit.	*T. Phillipsiana*-beds.
		Bourguetia-beds.
		Witchellia-beds.
	Notgrove Freestone (a remnant).	Notgrove Freestone.
	Gryphite-grit.	Gryphite-grit.
Upper *Trigonia*-grit. / Upper Freestone.	*T. Buckmani*-grit.	*T. Buckmani*-grit.
	Lower *Trigonia*-grit.	Lower *Trigonia*-grit.
	Snowshill Clay[1] (a trace).	Snowshill Clay.
		Harford Sands.
	Upper Freestone.	Upper Freestone.

The interest which attaches to the exploration of the North Cotteswolds is to ascertain how and in what manner this intervention of strata continues in a farther north-easterly traverse. The results are these:—That the three upper intervening beds at Cleeve Hill—the *Phillipsiana-Witchellia*-beds—have been planed away, so that Upper *Trigonia*-grit rests upon Notgrove Freestone; but in the lower part of the intervening series there has been a considerable development of strata, so that an important series of deposits separates the Lower *Trigonia*-grit from the Upper Freestone. Other results are that the Lower *Trigonia*-grit is very considerably altered in lithic character, and that in the south-eastern part of the district there has been removal of beds below the *Witchellia*-grit, with the consequence that the Upper *Trigonia*-grit rests upon Snowshill Clay.

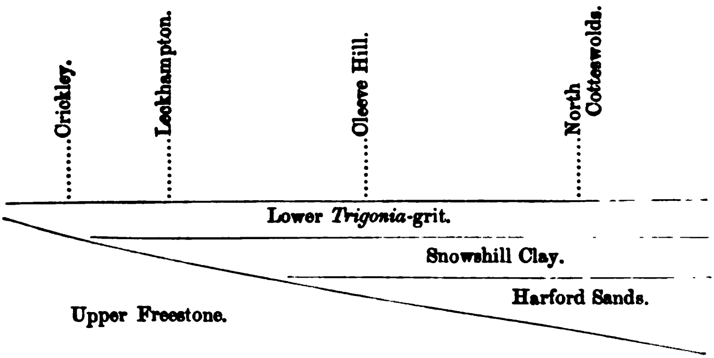
What these results indicate are as follows:—After the deposition of the Upper Freestone there was denudation of the deposited strata, with greater erosion south-westward. Then there was gradual depression producing overlap of deposits,—the Harford Sands being deposited over the North Cotteswolds as far as Cleeve Hill, but not beyond; the Snowshill Clay being deposited over a wider area,

[1] Entered in the paper on 'The Mid-Cotteswolds' as Harford Sands equivalent; afterwards distinguished and corrected, see paper on 'The Cleeve Hill Plateau' Quart. Journ. Geol. Soc. vol. liii (1897) p. 611.

for it stretches to Leckhampton Hill; the Lower *Trigonia*-grit reaching farther—its lower part, however, not extending to Crickley, near Birdlip, though the rest of it does.

The position of affairs may be roughly indicated in the appended diagram (fig. 1):—

Fig. 1.



After the Lower *Trigonia*-grit had been laid down, there was continuous deposition of other strata, until the *Phillipsiana*-beds of Cleeve Hill had been laid down. Then there occurred another—the Bajocian—denudation, which again was most effectual in the Birdlip district, where it removed a whole series of beds down to, and perhaps lower than, the originally denuded Upper-Freestone surface. When deposition again set in, and the Upper *Trigonia*-grit was laid down, this deposit necessarily rested upon a denuded surface of the outcrops of diverse rocks.

II. Cause of the Bajocian Denudation.

In my paper on 'The Mid-Cotteswolds' (p. 431), I spoke of the Bajocian denudation as having cut out a wide, shallow trough through the intervening beds of the Birdlip district. I was inclined to think that the strata had not properly consolidated, and that current-action might have swept away accumulations in certain places. But I have found evidence that the strata just deposited had consolidated. I obtained from the Cleeve-Hill plateau a bored piece of *Phillipsiana*-beds, where the borings pass through shell and stone equally: that implies that the stone was as hard as the shell, otherwise the shell would have been avoided. The beds, therefore, were thoroughly consolidated before the denudation.

Then Prof. T. T. Groom, writing to me about my Mid-Cotteswold paper, suggested that the previously-deposited strata had been thrown into folds whereof the anticlines had suffered denudation,

otherwise the Upper *Trigonia*-grit would have been deposited in the hollows. I was indisposed, however, to accept this argument, because the hollows found were so slight (they have only a fall of 7 feet per mile) that the surface would have been sufficiently horizontal to allow of the Upper *Trigonia*-grit resting there.

But there are other points to be considered besides the matter of consolidation. I have now found, by researches over a larger area, that the denudation of Jurassic rocks affected both England and Normandy, and that so far as the South-west of England is concerned, the lines of denudation fall into a fairly definite series of curves. Therefore I am inclined to accept, and very gratefully to acknowledge, Prof. Groom's suggestion. And I would put the matter in this way. During the deposition of the Bajocian, and at other times, small earth-movements occurred which threw the Jurassic rocks into folds of extremely slight elevation, in, probably, a very shallow sea. The anticlinal folds were denuded, and thus the edges of various deposits were cut across, exposed, and bored, and upon the surface so formed a deposit such as the Upper *Trigonia*-grit was laid down.

There were evidently two such periods of earth-movement and denudation during the deposition of the Inferior Oolite of the Cotteswolds,[1]—one after the deposition of the Upper Freestone; another after the deposition of the *Phillipsiana*-beds. The latter was the most important: it extended into Normandy. At Sully, near Bayeux, are pebbles containing ammonites of the *Sauzei-Witchelliæ* hemeræ—date of the *Phillipsiana*-to-*Witchellia*-beds of Cleeve Hill. Then at the base of the 'Oolithe ferrugineuse' is a kind of remanié deposit with Stepheocerata; and then deposition proper commences with the 'Oolithe ferrugineuse' of the *niortensis* hemera—that is, it commences at an earlier date than in the Cotteswolds, for the Upper *Trigonia*-grit is one hemera later, namely *Garantianæ*. Still the recommencement is only local in Normandy. About 7 miles away from Sully, between Port-en-Bessin and Ste. Honorine des Perthes, there is no 'Oolithe ferrugineuse,'—the recommencement of deposition started with strata of *Truellii* hemera. The advance of deposition was slowly towards the north-west, indicating where the anticline might be expected.

III. Generalized Section of the North Cotteswolds.

A generalized section of the deposits found in the main mass of the North Cotteswolds may now be given, and then the details of the different sections which afforded the evidence whereon it is constructed.

[1] Similarly in Somerset and Dorset; see Appendix II, p. 153.

Generalized Section of the North Cotteswolds.

Formation.	*Thickness in Feet.*	*Localities.*
I. Upper *Trigonia*-grit.	6	Above Snowshill; Farmcott Wood; near Campden Hill Farm; Bourton Clump.
V. Notgrove Freestone.	25	Above Snowshill; Farmcott Wood; near Campden Hill Farm; Snowshill—road to Broadway Tower.
VI. Gryphite-grit ...	$3\frac{1}{2}$	Sudeley Hill.
VII. *T. Buckmani*-grit.	10	Sudeley Hill.
VIII. Lower *Trigonia*-grit.	7 to 10	Sudeley Hill; Stanway Hill.
IX. Upper Snowshill Clay.	15 to 20	Stanway Hill; Seven Wells. Generally in neighbourhood of Broadway Tower.
IX*a*. Tilestone	About 15	Bourton Clump; near Hyates Pits; Guiting Hill.
IX*b*. Lower Snowshill Clay.	5	Bourton Clump; Guiting Hill.
X. Harford Sands.	10, or perhaps more.	Near Snowshill; Bourton Clump; Upton Wold; Sudeley Hill.
XI. Upper Freestone.		

IV. Detailed Sections in the North Cotteswolds.

The following sections give the evidence upon which the generalized section has been founded. The first section is nearest to Cleeve Hill, and has necessarily most affinity therewith. It is as follows:—

Section I.—*Farmcott Wood and Sudeley Hill.*
(From Winchcombe $1\frac{1}{2}$ miles east, by the side of the main road to Stow.)

A. Farmcott Wood.

		Ft.	Ft.
Upper *Trigonia*-grit.	I. 1. Shelly limestones with earthy partings: numerous *Trigoniæ* (moulds) and the characteristic brachiopoda		6
Notgrove Freestone.	V. 1. Whitish, very oolitic stone, with a planed and bored surface. Level-bedded	$6\frac{3}{4}$	
	2. The same, but very noticeably false-bedded ....shown	8	
	Add about 10 feet for the difference in ground-level between this exposure and the next. Probably some feet more should be added for the dip	$10\frac{1}{4}$	
		—	25

B. Sudeley Hill.

		Ft.	Ft.
Notgrove Freestone.	V. Fragments in soil.		
Gryphite-grit.	VI. 1. Yellowish marl and stone; broken fragments of *Gryphæa*	1½	
	2. Shelly ragstone, with numerous *Gryphææ*; and with *Belemnites gingensis* near the top	2	3½
T. Buckmani-grit.	VII. 1. Yellowish, sandy stone with *Trigoniæ*; *Terebratula Uptoni*, 3 feet down; *T. Buckmani*, single, 4½ feet down. The top of this series is a somewhat hard, projecting bed. Visible	8	
	Add perhaps	2	10
Lower *Trigonia*-grit.	VIII. Hard, brown-speckled, somewhat sandy stone. *Ostrea*; smooth *Pecten*; very large *Cucullæa*. Lower 2½ feet visible in the quarry at a waggon-loading ledge. Possible thickness		7
	[The part above the 2½ feet is hidden by rubble over the face of the quarry.]		

NOTES.—Some 20 feet lower down the hill is an exposure of what look like Harford Sands, near the bench-mark 920, on the right-hand side of the road to Winchcombe. There is an undoubted exposure of these sands in a rabbit-burrow, in the copse under the steep brow of the hill to the left. This is at about the same level. The sandstone is crowded with lamellibranchs. A measurement makes it 45 feet below the Notgrove Freestone. About another 25 feet lower is an exposure of Oolite-Marl with *Terebratula fimbria*.

In the main, the strata at Farmcott and Sudeley Hill correspond with the Cleeve-Hill and Mid-Cotteswold sections, but the lithic character of the Lower *Trigonia*-grit has altered somewhat. The horizon with *Terebratula Uptoni* is very useful for comparison with Leckhampton Hill, and gives a datum-line at once. *Belemnites gingensis* is also a good fossil by which to distinguish a particular horizon.

It may be noticed that we have lost the *Phillipsiana* to *Witchellia*-beds found at Cleeve Hill 3½ miles to the west. Their limits can be very precisely defined. Thus at Cotehay Farm the top layer of the *Bourguetia*-beds is bored—the *Phillipsiana*-beds have gone. At Rowell Gate the Notgrove Freestone is bored: the *Bourguetia*- and *Witchellia*-beds, therefore, disappeared in the Charlton Abbots Valley.

In the next sections the lithic character of the Lower *Trigonia*-grit is altered entirely; but *Hyperlioceras* defines the horizon. These sections carry the strata farther down, and show the sequence.

Section II.—*Stanway Hill.* (From Winchcombe 3½ miles N.E. by E., by the side of the Old Campden Road.)

		Ft.	ins.	Ft.	ins.
T. Buckmani-grit.	VII. 1. Stone with marl; *Gryphæa* and *Ostrea*.			5	0
Lower *Trigonia*-grit.	VIII. 1. Stone with *Hyperlioceras(?)* in section		8		
	2. Marl with *Hyperlioceras* (B).	1	0		
	3. Rubbly stone.....................		9		
	4. Marl and stone	2	0		
	5. Whitish stone	3	0		
	6. Slightly ironshot stone.........		6		
				7	11
Snowshill Clay.	IX. 1. Dark clay-band (1), *Belemnites*..............		3		
	2. Dark ironshot marl		4		
	3. Brown ironshot stone		5		
	4. Dark ironshot marl, '*Graphoceras*' sp., *Belemnites*, *Ostrea Marshii* (A)..............		6		
	5. Brown ironshot limestone ...	1	6		
	6. Yellow sandy clay...............		3		
	7. Very ironshot marly stone, coarse grains of limonite ...		9		
	8. Finely laminated bluish-yellow clay	1	5		
				5	5

Notes.—A lump of Oolite-Marl matrix was found at the entrance to the quarry. The Snowshill-Clay deposits are interesting and fossiliferous. It is unfortunate that their further development downward is hidden by much fallen débris, for I have not yet discovered any exposure of these rocks with similar characters. The bed IX 7 is a remarkable kind of pisolitic ironstone, different from any other bed in the Cotteswolds.

The '*Graphoceras*' sp. is interesting, bearing out the suggestion made in former papers as to the date of the Snowshill Clay—that it was of *concavi* hemera. It is not a true *Graphoceras*, not having a proper V-script radial line, and it is a species different from any one obtained from Dorset or Somerset. It is, however, a Graphoceratoid, and has a coucavumbilicus; moreover, it is akin to certain species found in the *concavi* hemera of Dorset. As ammonites are very scarce in the Cotteswold Inferior Oolite, the find is very satisfactory.

The next section—exposures near the top of Stanway Hill, on the old road from Tewkesbury to Moreton-in-the-Marsh—supplies a few additional details.

Section III.—*Stanway Hill.* (Near the old road to Stanway Village, ½ mile north of the foregoing exposure.)

T. Buckmani-grit.	In the quarry.
	Ragstone with *Belemnites insculptus* and *B. gingensis*.
	Unseen—to road.
	By the side of the road.
Snowshill Clay.	Brown ironshot stone like A in the other quarry.
	Bluish clay.
	A coarsely oolitic, somewhat ironshot freestone.
Tilestone equivalent (?)	A fine-grained freestone.
Harford Sands.	Indications of sand.

Somewhat between Farmcott Wood and Stanway Hill is an exposure which evidently carries matters below the Harford Sands, but it does not touch Oolite-Marl, whereof there was some indication at Stanway Hill.

SECTION IV.—*Pinnock Farm.* (From Winchcombe 2½ miles east.)

		Evidence of clay.	Ft.	ins.	Ft.
Harford Sands.	X.	1. Whitish sands	5	0	
		2. Layer of white calcareous matter.		2	
		3. Marly layer		6	
					5⅔
Upper Freestone equivalent (?)	XI.	1. Freestone	4	0	
		2. White stone, with layers of whitish calcareous sand. Stone about 10 inches and sand about 4 inches each	6	0	
					10

NOTE.—Compare XI 2 with X 2 of Section IX at Upton Wold Farm, p. 135.

Some 2 miles north-east of Stanway Hill, along the Old Campden Road, is found an interesting section. The Upper *Trigonia*-grit rests upon a thick mass of freestone, which contains often in some abundance, especially in other quarries near, a *Pecten* of the *P. personatus*-type.

SECTION V.—*Above Snowshill.* (Between the Old Campden Road and the village.)

			Ft.
Upper *Trigonia*-grit.	I.	Rubbly, in places marly, ironshot stone like the Upper *Trigonia*-grit at Harford and near Notgrove. *Rhynchonella subtetrahedra*, *Rh. hampenensis*, *Pecten lens*, *Homomya*	6
Notgrove Freestone.	V.	Freestone with *Pecten personatus (?)* and *Trigonia signata*. This is much bored at the top, and exhibits a planed-off surface, covered with oysters	25

The following section gives evidence, from two exposures, of the presence of Harford Sands below the *Pecten-personatus* Freestone, which is important:—

SECTION VI.—*Snowshill.* (Road to Broadway Tower.)

			Ft.	Ft.
		Quarry on the north.		
Notgrove Freestone.	V.	Whitish, glistening stone. *Pecten personatus (?)* numerous...... about		10
Unseen.		Invisible many feet down to the		
		Quarry on the south.		
		The soil seems clayey.		
Harford Sands.	X.	Sandy loam	2½	
		Sandy rock with numerous *Nerinæa* of various species	2¼	
		Fine white quartzose sand, with grains of mica (?), and some calcareous portions	3½	
				8¼

The Harford Sands show that the Freestone with '*Pecten personatus*' cannot be the Upper Freestone where it immediately underlies the Upper *Trigonia*-grit: it is evidently Notgrove Freestone.

Another mile on the Old Campden Road is Seven Wells. This locality takes its name from the fact that the Snowshill Clay throws out water copiously here. The following details may be noted:—

Section VII.—*Seven Wells.*

Snowshill Clay.	IX.	The fruit-trees near the farm mark the line of Snowshill Clay. Perhaps as much as 20 feet of it.
Tilestone equivalent (?)	IXa.	Below that is some stone, perhaps more or less mixed with clay.
Harford Sands.	X.	These are exposed in the field some 25 feet lower.

Just south of Broadway Tower, which is about 1 mile north of Seven Wells, distinctive evidence of Snowshill Clay and Harford Sands abounds. It would be quite easy to map them around here. Besides exposures, the ploughed fields, the furze, the thorns, the oak-trees show the limits of one or the other, as the case may be. There must be a very considerable thickness of these two deposits. And in a roadside exposure I found stone, evidently higher than the Snowshill Clay, which was in all likelihood Lower *Trigonia*-grit. Moreover, there is very likely Notgrove Freestone about here, for H. B. Woodward speaks of Freestone with *Pecten personatus* as occurring near the Fish Inn, Broadway.[1] Certainly he puts it below 'Oolite-Marl?'; but what Oolite-Marl is like in this neighbourhood is shown by the quarry near Chipping Campden, 1½ miles from Seven Wells on the Old Campden Road (see Appendix I, p. 150). Just before that exposure is a quarry showing Upper *Trigonia*-grit resting on freestone with *Trigonia signata*, which brings it into line with the Snowshill exposure. The latter is really the key to the whole.

Section VIII.—*Near Campden Hill Farm.* (South of Old Campden Road.)

			Ft.
Upper *Trigonia*-grit.	I.	Somewhat rubbly, yellowish crystalline stone, with *Rhynchonella subtetrahedra*, *Rh. hampenensis*, *Zeilleria Waltoni*, *Terebratula globata*, *Acanthothyris spinosa*	2¾
		(Parting conspicuous. Top planed off, pitted, covered with oysters, but not bored. An inconstant band of stone above, with oysters, is bored.)	
Notgrove Freestone.	V.	Whitish crystalline stone (*Trigonia signata*). Roadstone	7

Note.—Denudation prior to the deposition of the Upper *Trigonia*-grit was very irregular. Some of the stone is greatly pitted and bored by a large species of *Lithodomus*. There is a similar quarry near the Lodge on the left of the bye-road leading to Northwick Hill Farm.

[1] Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. iv (1894) 'Lower Oolitic Rocks of England' p. 140.

There are obviously strata (and farther south-east too, which is important) higher than Upper Freestone, yet which show no capping of Upper *Trigonia*-grit. That indicates that the freestone seen near Campden Hill Farm which is capped by Upper *Trigonia*-grit, must be later than Upper Freestone. In the margin of the following section I have placed the possible interpretation of the beds, though confessing that their exact position in the sequence requires more investigation:—

Section IX.—*Upton Wold Farm, Blockley.* (North of the Farm, 3 furlongs.)

			Ft.
Harford Sands (?)	X.	1. Disturbed stone, like the bed below, more or less mixed with soil	2½
		2. Grey stone, with partings of whitish-yellow sands, some partings 1½ feet thick......	13

Note.—Bed X 2 may be a local condition of Upper Freestone; but if Harford Sands, it indicates a very great thickening of the deposit. It may be compared with Bed XI 2 of Section IV, p. 133.

Farther south-east there is evidence, at Bourton Clump, that the Upper *Trigonia*-grit, though well separated from the Upper Freestone, does lie not far above the Snowshill Clay. There seems to be some irregularity about it, but it is probably not great; and the evidence points to Bajocian denudation having removed all from the Notgrove Freestone to the Lower *Trigonia*-grit, inclusive. This brings the section into line with the exposure in the cutting by Aston Farm, on the Banbury & Cheltenham Railway, where the Upper *Trigonia*-grit is separated from the Harford Sands by 4 feet of a kind of freestone. In the Bourton-Clump section it is separated by 7 feet of rock, but there may be a few feet more. The following is the section:—

Section X.—*Bourton Clump.*

			Ft.	ins.	Ft.
Upper *Trigonia*-grit.	I.	'Top beds,' with *Rhynchonella angulata*, *Terebratula globata*, etc., irregularly overlying the bed below. Perhaps a fault with some overthrust.			
Tilestone.	IX*a*.	1. Oolitic fissile stone, with small oysters			2
Lower Snowshill Clay.	IX*b*.	1. Brown and blue clay, stiff towards the top	3	6	
		2. Brown stone		2	
		3. Bluish-grey sandy clay	1	4	
					5
Harford Sands.	X.	1. Hard grey sandstone	1	5	
		2. Yellow sands	1	6	
		3. Oolitic marly stone	2	9	
					5⅔
Upper Freestone (?)	XI.	1. Whitish oolitic crystalline stone.			3

Note.—Bed XI. 1 may be the same as Bed X. 1 in Section IX, and then the Upton-Wold section would be a continuation of this one.

About ½ mile west of this, on the cross-road to Warren Farm, a quarry showed ragstone which seemed to be Lower *Trigonia*-grit; and a little more than ½ mile south-west on the main road, where Lodge is marked on the Ordnance Map, there is similar ragstone. If this be the Lower *Trigonia*-grit, the line marking the eastern limit of this deposit beneath the Upper *Trigonia*-grit can be drawn between these points and Bourton Clump, in continuation of the evidence of the Harford and Aston Cuttings on the Banbury & Cheltenham Railway.[1]

In the generalized section (p. 130) I have placed below the Lower *Trigonia*-grit and above the Upper Freestone the following strata:—

Upper Snowshill Clay.
Tilestone.
Lower Snowshill Clay.
Harford Sands.

The sequence of these strata was only very incompletely observed; and the thickness of the Tilestone could not be ascertained. The Bourton-Clump section supplies the evidence of Lower Snowshill Clay parting the Tilestone from the Harford Sands. That it is Tilestone the very small *Ostreæ*, which are very distinctive thereof, seem to indicate.

The Tilestone is best developed near the line of the old British road, the Buggilde Street (see Map, Pl. VI), which runs northward from Bourton-on-the Water over Cutsdean Hill past Hyates Pits, and joins (or rather crosses) the Old Campden Road, another British trackway, just beyond Snowshill. At Hyates Pits, and between Horns Leazor and Scarborough Barn, were quarries where this stone was formerly worked. It is a very fissile rock, characterized by numerous small *Ostreæ*; and it was used for roofing-tiles for buildings. But the use of it has been discontinued now, and the pits are filled in. I found in the neighbourhood the following section, which gives evidence of clay above the Tilestone; and at Small Thorn, at a higher level, there is evidence of a considerable development of Snowshill Clay.

SECTION XI.—*Cross-roads ¾ mile south of Hyates Pits, and about ½ mile from Scarborough Barn.*

			Ft.
Upper Snowshill Clay.	IX.	1. Clay, from evidence of infillings.	
Tilestone.	IX*a*.	Fissile stone with small *Ostreæ* .... about	14

NOTE.—I presume that the fissile stone was formerly worked for roofing-tiles. This seems to be the same bed as that at Hyates Pits.

Then 1½ miles farther south, there is evidence of a rock like the Tilestone, overlying some clay-beds.

[1] See 'Cleeve Hill Plateau' Quart. Journ. Geol. Soc. vol. liii (1897) pl. xlvi, map of the Bajocian denudation. Then the Oolite-Marl line would run northward parallel with this, and not so much to the east as on that map. A revised edition of the map is issued with this paper, see Pl. VI.

Section XII.—*Guiting Hill.* (About ½ mile south of Trafalgar Farm.)

			Ft. ins.	Ft.
Tilestone. equivalent?	IX *a*.	Somewhat fissile oolitic stone ...	8 0	
			——	8
Lower Snowshill Clay.	IX *b*.	1. Clay-seam, inconstant	2	
		2. Fairly hard ragstone	1 8	
		3. Clay and stone at the bottom of the quarry; the clay holds water .... visible	6	
			——	2⅓

About 4½ miles south-south-east, the Harford cuttings show some 5 feet of a freestone characterized by small *Ostreæ*, overlying the Harford Sands. I presume this is the same bed in an attenuated condition, and without any distinct deposits of Snowshill Clay. So that on the Banbury & Cheltenham Railway at Harford the deposits are:—

Lower *Trigonia*-grit.
Freestone (equivalent of the Tilestone).
Harford Sands.

But on the south-east, at Cleeve Hill the deposits are:—

Lower *Trigonia*-grit.
Snowshill Clay.
Harford Sands.

And farther away, at Leckhampton Hill, there is Lower *Trigonia*-grit, only a trace of Snowshill Clay, and no true Harford Sands.

If the position of the Tilestone above the Harford Sands be correct, it was quite to be anticipated that it would not be found to extend to Leckhampton Hill. It might have been expected, however, at Cleeve Hill, though in an attenuated form, as at Harford. But there is every reason to suppose that this Tilestone, in what may be called a recognizable thickness, is a particularly local deposit, only fully developed in that district of the North Cotteswolds which borders the Buggilde Street.

The recognition of the Tilestone as above the Harford Sands, and distinct from the Upper Freestone, is an interesting point; and it would be desirable to have more information on the matter. The sequence of these deposits certainly requires to be worked out in more detail. The position of the beds shown in Section IX requires to be better established.

I measured with a level some exposures at Sudeley Hill, with the following result:—

	Ft.
From Notgrove Freestone to Harford Sands	45
From Harford Sands to Oolite-Marl with *Terebratula fimbria*	25

From the 45 feet may be deducted 20 feet for ragstones (see Section I B, p. 131), and so the results would be:—

	Ft.
(1) Ragstones (*Gryphæa*-, *T. Buckmani*-, and Lower *Trigonia*-grits as in Section I B) .... about	20
(2) Snowshill Clay, Tilestone or its equivalent, and Harford Sands	25
(3) Upper Freestone, and perhaps some Oolite-Marl...	25

Division 2 thins out to about 6 feet at Cleeve Hill, but there is reason to suppose that it thickens rapidly eastward (see fig. 3, p. 142).

V. Supplementary Notes.

(a) The Snowshill Clay.

The recognition of this clay as a water-retaining bed might be of some economic importance to the district. It has been noticed already as the factor in holding up water for the supply of Seven Wells Farm; and as furnishing soil suitable for fruit-trees. It would probably be found that the position of several other farms had been determined by this clay, which is certainly a thick deposit. Such position at any rate is the case with a farm known as Small Thorn, and its neighbour, about ¼ mile away, Bourton Hill (not marked on the map).

I obtained the following information at Small Thorn:—

'The well is 6 feet deep, and there are springs of water in the fields; but at Bourton Hill the well is 40 feet deep. At Small Thorn the water has shrunk a bit of late' [August 1898—a very dry summer. They attribute the shrinkage to the waterworks at Kitenest, near Broadway, but these are in Lias.]

'At Small Thorn they always have plenty of water, but in the bottom (that is, on Upper Lias at Horns Leazor) they have none now [in summer]. Yet in the winter the latter is flooded.'

(b) The Harford Sands.

These sands form a very noticeable deposit in the North Cotteswolds, and attention may be called to the fact that they are, in places, very fossiliferous. Thus at Snowshill (Section VI, p. 133) they showed abundance of *Nerinæa* of various species; and at Sudeley Hill, on the flank of the escarpment below Farmcott-Wood Quarry, the sandstone-blocks were quite crowded with lamellibranchs.

(c) A Review of Work accomplished.

This paper concludes, with the former contributions published in the Society's Quarterly Journal [1] and two communications published in the Proceedings of the Cotteswold Naturalists' Field Club,[2] the description of the Cotteswold strata intervening between the Upper *Trigonia*-grit and the Upper Freestone. The papers published in the Quarterly Journal may be said to form a monograph upon the subject of these intervening beds and the Bajocian denudation; but those published by the Cotteswold Field Club, dealing with the strata on the two lines of railway, were not written from this special point of view. They are moreover deficient in details, owing to

[1] 'Mid-Cotteswolds' Quart. Journ. Geol. Soc. vol. li (1895) pp. 388–462 & 'Cleeve Hill Plateau' *Ibid.* vol. liii (1897) pp. 607–29.

[2] 'The Inferior Oolite between Andoversford & Bourton-on-the-Water' Proc. Cottesw. Nat. F. C. vol. ix (1887) p. 108; 'The Sections exposed between Andoversford & Chedworth' *Ibid.* vol. x (1890) p. 94.

lack of insight as to the identification of strata, which was gained by subsequent research. To complete the subject of the development of the intervening beds in the Cotteswolds, and the effects of the Bajocian denudation, I may give here a summary of the stratal development along the Banbury & Cheltenham Railway in comparison with Cleeve Hill. A revised section of the strata on the other line of railway, at Chedworth Wood, was published in 'Mid-Cotteswolds,' p. 425.

	Cleeve Hill. Ft.	ins.	Notgrove Station.	Harford Cutting.	Aston Farm.
Phillipsiana-beds ...	10	1	None.		
Bourguetia-beds	13	6	None.	None.	None.
Witchellia-bed	4	0	None.		
Notgrove Freestone ...	20	0 (about)	19¾	Ft. 8	None.
Gryphite-grit	5	0	3 incomplete.	10	None.
T. Buckmani-grit ...	17	0 (about)			
Lower *Trigonia*-grit .	7	0 (about)			
Snowshill Clay	1	4	......	None.	None.
			Tilestone.	Ft. 5	Ft. 4
Harford Sands	5	0	......	6¼	4¾

The result is that in an east-by-south traverse from Cleeve Hill the *Phillipsiana*-to-*Witchellia*-beds soon disappear. The Notgrove Freestone extends for some distance in contact with the Upper *Trigonia*-grit, but is distinctly thinner at Harford cutting than at Notgrove Station. Then there is a rapid disappearance, and the Upper *Trigonia*-grit is found resting nearly on Harford Sands within a short distance.

Farther in the same direction more disappearance takes place. At Little Rissington the *Clypeus*-grit is almost in contact with the Upper Lias. And then the Upper Lias becomes gradually less, for Prof. Hull says:[1]

> 'At Knot Nook, on the borders of Wychwood Forest, I found Inferior Oolite lining the sides of the dell, of which Marlstone formed the bottom, with scarce a trace of Upper Lias Shale between [them].'

I have not been able to locate the place exactly, but it is evidently in the same direction.

All these observations show a continuous denudation of strata, in passing from Cleeve Cloud in a direction east-by-south. Their significance may be considered more fully in connection with what is found in the North Cotteswolds, to which attention may now be directed.

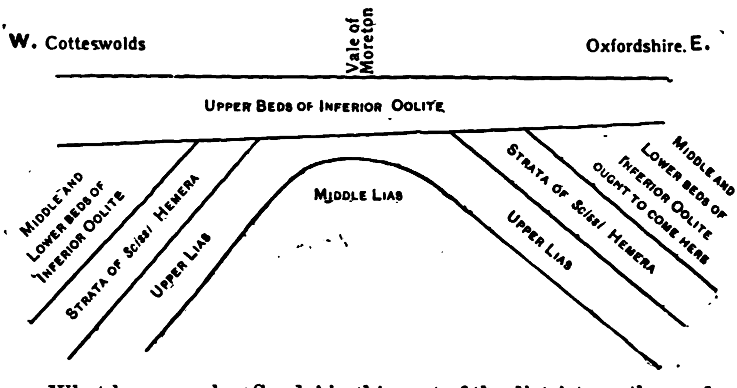
[1] Mem. Geol. Surv. 1857, 'Geol. of Country around Cheltenham' p. 25.

(*d*) Section through the North Cotteswolds, from west to east.

Results similar to those just detailed are found to obtain in making a west-to-east traverse of the North Cotteswolds. The *Phillipsiana*-to-*Witchellia*-beds soon disappear. Then the Notgrove Freestone comes into contact with the Upper *Trigonia*-grit, and remains so over some distance; then rather suddenly on the east flank of the North Cotteswolds—overlooking the Vale of Moreton—there is disappearance of the lower Inferior-Oolite beds, until the upper Inferior-Oolite beds rest directly upon Upper Lias. Then the Upper Lias itself suffers denudation, for according to Hull 'at Stow the average thickness is 40 feet.'[1] But eastward it thickens again: 'at Chastleton it is 60 feet.' That indicates that the axis of the anticline, evidenced by the greatest amount of denudation beneath upper Inferior-Oolite beds, is in the Vale of Moreton, between Stow and Chastleton; and that, at Chastleton, the eastern side of this anticline is to be found. Further evidence of this is given by Hull. He says (*op. cit.* p. 30):

'East of Stow the Sands disappear and we only find them once, namely, at Cornwell around the Chastleton outlier.'

Fig. 2.—*Diagrammatic section across the Vale of Moreton.*



What he means by 'Sands' in this part of the district are the sandy ferruginous beds above the Cephalopod-bed—the strata deposited during the *scissi* hemera (see Appendix I *d*, p. 151). And what his statement indicates in the present connection is that at Cornwell, east of Chastleton, the lower beds of the Inferior Oolite—these sandy ferruginous strata—are coming in again. I know, from fossils which Mr. E. A. Walford, F.G.S., has sent me from Hook Norton, that beds of this date—*scissi* hemera—are found there, which is confirmatory evidence in the same direction.

The above diagram (fig. 2) shows the position of affairs west and east of the Vale of Moreton, and of the anticline which was

[1] Mem. Geol. Surv. 1857, 'Geol. of Country around Cheltenham' p. 25.

denuded prior to the deposition of the upper beds of the Inferior Oolite. The western portion shows what has actually been found; the eastern part, so far as Upper Lias and strata of *scissi* hemera are concerned, what is the interpretation of Prof. Hull's observations and of Mr. Walford's finds. Then we may expect to find in Oxfordshire a coming-in, as we go down the syncline, of the other beds of the Inferior Oolite, in the order in which they disappeared west of the anticline. But this may be complicated by the fact that there was more than one denudation—one prior to *scissi* hemera, one *post-bradfordensis* (after Oolite-Marl), and one prior to *Garantianæ* (Upper *Trigonia*-grit): see Appendix II, p. 152. But there is little doubt that the interpretation of the Oxfordshire strata is this—that the beds of the Inferior Oolite reappear more or less completely, representing those of the Cotteswolds which are found to disappear.

An extended diagram (fig. 3, p. 142) of the strata across the North Cotteswolds may now be given, and calls for the following remarks:—

It proposes to be no more than a generally approximative diagram. The thick waved line represents the contour, roughly, of the present-day surface. The thick lines between beds indicate lines of denudation. The horizontal thick line beneath the Upper *Trigonia*-grit is taken as a base-line.

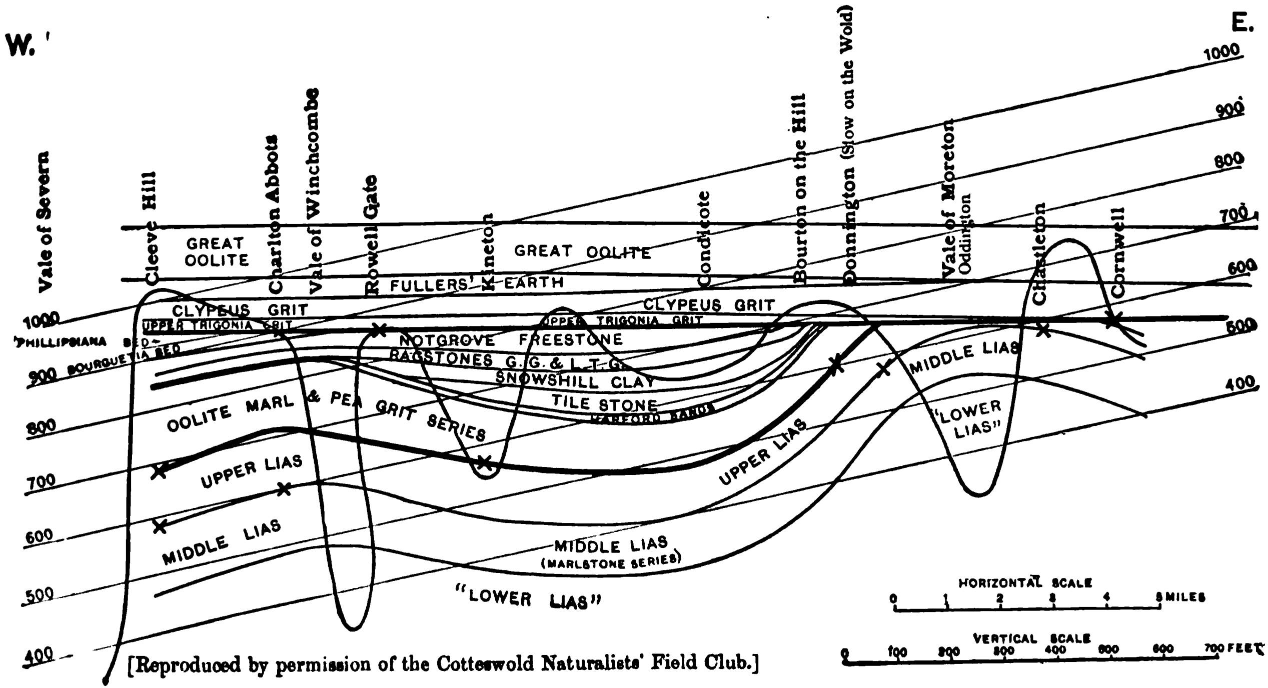
The section is drawn from Cleeve Hill to Chastleton, though of course some evidence has had to be obtained from places a little way off the direct line.

As to the evidence, especially of the syncline between Rowell Gate and Donnington:—The *Phillipsiana*-to-*Witchellia*-beds disappear before Rowell Gate, indicative of an easterly rise in that distance (relative to the Upper *Trigonia*-grit line) of about 30 feet. Confirmatory of this surmise, though not of much value alone, is the slightly higher position, actually, of the Marlstone in the Winchcombe Valley than on the western face of Cleeve Hill. Even a dead level, without an easterly dip, would be enough for the purpose.

If, however, the rise, by which the *Phillipsiana*-to-*Witchellia*-beds disappear, had been maintained, then the Notgrove Freestone should disappear about at Rowell Gate, and most of the Inferior Oolite should disappear shortly afterwards. Such is not the case. The Notgrove Freestone maintains its position for a long distance. I surmised, to account for this, that there must be a syncline between Rowell Gate and Donnington. I tried the position of the Upper Lias in the only available intermediate place, the Kineton Valley, and found that it was about 130 feet lower there than on the western flank of Cleeve Hill, the top of it being actually lower than the bottom of it in the Winchcombe Valley.

Such difference of level exactly suits the hypothesis of a syncline. Too much importance cannot be attached to it. It may be of Tertiary date; or it may be, as I have supposed for my purpose, what may be called pre-Bathonian. Assuming that it is so, it fits the theory of a syncline excellently. With such a syncline, however, the Notgrove Freestone should dip, and the *Phillipsiana*-to-*Witchellia*-beds ought to come in again east of Kineton. There

Fig. 3.—*Diagrammatic section across the North Cotteswolds, from west to east, showing the strata upon which the Upper* Trigonia-*grit was laid down.*



[Reproduced by permission of the Cotteswold Naturalists' Field Club.]

is no evidence that they do; and actually it better fits the facts that they do not.

In the early part of the paper I noted the considerable development of the Snowshill Clay, Tilestone, and Harford Sands. My field-measurements (admittedly incomplete) assigned to them a minimum thickness of 50 feet. Now that I have drawn the diagram, I can understand that a thickness of 100 feet may be possible. At any rate, a considerable development of these beds in the Kineton area exactly fits: (1) the persistence of the Notgrove Freestone; (2) the syncline between Rowell Gate and Donnington; while the syncline accounts for the much greater rapidity of the disappearance of strata in the Bourton-on-the-Hill neighbourhood than in the Cleeve-Hill district.

A further remark may be made. The present height of the Marlstone above sea-level is very nearly the same on the west flank of the North Cotteswolds as on the east flank overlooking the Moreton Vale: it is in close approximation to the 600-foot contour-line. But the level of the Upper *Trigonia*-grit is very different. It is more than 1000 feet above sea-level on the west flank, and it is about 700 feet above sea-level on the east flank. If then the Upper *Trigonia*-grit was laid down on a level surface, as shown in the diagram, then at that date the Marlstone dipped westward from the Vale of Moreton, and was some 300 feet lower on the west flank than on the east. The Tertiary elevation of the country brought the Marlstone up to be nearly level, and tilted slightly the Upper *Trigonia*-grit.

In fig. 3 the present contour-lines are drawn askew. By placing these contour-lines horizontally, the present-day position of the strata may be observed. By placing the Upper *Trigonia*-grit line horizontally, the position of affairs at the time of the deposition of that bed will be seen, and that is the position which the diagram is designed to illustrate.

I would now draw attention to the great difference that exists between the west-to-east section of the Cotteswolds which I have given, and that put forward by Hull and other authors, wherein a gradually progressive diminution, not only of the Inferior-Oolite rocks, but of Middle and Lower Lias, is assumed.

(*e*) Comparison with Prof. Hull's Section.

In the sections given by Hull[1] there are the following results, approximately:—At Leckhampton, Inferior Oolite 230 feet, Upper Lias 200, Marlstone 120, Lower Lias (partly shown) said to be 600 feet (*op. cit.* p. 15)—the total about 1150 feet; but at Burford the whole, from the top of the Inferior Oolite to the (assumed) base of the Lower Lias is made only 150 feet. This extraordinary result is supposed to constitute the thinning-out of the Jurassic rocks to the eastward. It has been generally accepted, for H. B. Wood-

[1] Mem. Geol. Surv. 1857, 'Geol. of Country around Cheltenham' pl. ii.

ward gives a section drawn by W. Topley, from Leckhampton Hill to Burford,[1] where this remarkable thinning-out is shown, the Keuper strata being actually brought up at Burford to about 250 feet above sea-level, as in Hull's diagrams!

Prof. Hull seems to have assumed this general thinning 'from analogy' (*op. cit.* p. 15).[2] He explains this rather more fully in other places. He found, eastward, a disappearance of all middle and lower beds of the Inferior Oolite, and a very great reduction in the thickness of the Upper Lias. He then seems to have 'assumed' that all other Jurassic beds in the district thinned-out proportionately—that because the Inferior Oolite was reduced from 230 to about 20 feet on the east, therefore the Lower Lias must be reduced from 600 to about 50 feet. The great mistake arose from thinking that the difference in the thickness of the Inferior-Oolite rocks had been produced by diminution in amount deposited. It was really brought about by contemporaneous erosions—the principal of which was the one that occurred before the deposition of the Upper *Trigonia*-grit. This erosion planed away the strata of the Middle and Lower Inferior Oolite and of the Upper Lias in an easterly direction until the lowest limit is reached in the Vale of Moreton; and eastward of that the strata begin to reappear in succession—for instance, the Upper Lias thickens, the strata of the *scissi* hemera come in, and there are certainly other rocks of the Inferior Oolite.

The idea that the rocks of the Inferior Oolite or Upper Lias thin gradually in passing from west to east must be kept quite distinct from the idea that alterations in their thickness have been brought about by what may be called penecontemporaneous denudation. In the former case, the supposition of analogous and continuous thinning of Middle and Lower Lias might be justified. In the latter case, it would be an unwarranted surmise. And the former case does not fit the facts, as detailed in this paper; for the greatest thickness of strata of the Inferior Oolite yet met with is evidently in the neighbourhood of the Buggilde Street, near Cutsdean Hill, not westward, at Cleeve Hill.

In the neighbourhood of the Buggilde Street there is a development of about 50 feet, or perhaps more, of the Snowshill Clay and Tilestone series. Against that must be set a loss of about 30 feet by removal of the *Phillipsiana-Witchellia* series. So there is a gain of about 20 feet, in that way. The actual thickness of the

[1] 'Geology of England & Wales' 2nd ed. (1887) p. 280.

[2] [See also the same author's paper 'On the South-easterly Attenuation of the Lower Secondary Formations of England' etc. Quart. Journ. Geol. Soc. vol. xvi (1860) p. 70, which I had overlooked when writing. There he says: 'If it can be shown that there is a tendency on the part of the Marlstone and Upper Lias to thin away towards the south-east, and that this attenuation takes place within the range of actual observation, there will be strong grounds for inferring a similar propensity on the part of the Lower Lias; at least, it is upon these grounds that I base the analogy.'—*January 22nd*, 1901.]

Cleeve-Hill strata cannot be told by direct measurement, because of faults. That of Leckhampton can; and therefrom the thickness at Cleeve Hill can be estimated.

Hull says that the thickness of Inferior Oolite at Leckhampton Hill is 236 feet.[1] That does not include the *Clypeus*-grit, which is about 15 feet thick; the total then would be 251 feet. But at Cleeve Hill there are, in addition, *Phillipsiana*-to-*Witchellia* beds, 27 feet; excess of Notgrove Freestone, 20 feet; Snowshill Clay and Harford Sands, 6 feet. These are all additions at Cleeve. The Cleeve total, then, is 304 feet. This thickness by no means decreases eastward. In the hills to the east of Cutsdean, whereon runs the Buggilde Street, there is, according to the contour-map, above Temple Guiting, about 250 feet of Inferior Oolite, only up to Snowshill Clay; and from Cutsdean Bottom to Cutsdean Hill 300 feet, without the series being complete. There is reason to believe the total thickness not far short of 350 feet near Cutsdean, and even then the 27 feet of the *Phillipsiana*-to-*Witchellia* beds are wanting.

Taking only the additional amount, obtained just now, of 20 feet extra, as balance of gain and loss, in the Kineton neighbourhood as compared with Cleeve, that would make 324 feet. But actually several deposits are known to thicken eastward. The *Clypeus*-grit thickens very considerably in the Notgrove neighbourhood, as compared with the west flank—say 15 feet. The Notgrove Freestone thickens in the Chedworth district in similar comparison. The lowest beds—the strata of the *scissi* hemera, which Hull mapped as sands—are many feet thick in the Kineton district. They are only a small bed merged in the Pea-grit Series at Leckhampton.

There is every reason, then, to think that 350 feet in the Cutsdean district is an under-estimate. Yet almost due south, at Turkdean, Hull gives 70 feet as the thickness of Inferior Oolite; but this decrease is not due to thinning-out, it is due to denudation of an anticlinal fold.

Since, therefore, the thinning of the Inferior Oolite from west to east is not what may be called normal, but is really abnormal, local, and due to chance anticlinal elevations, it follows that Hull's surmise of analogous and continuous thinning of the Lias could not be estimated from any ratio of Inferior-Oolite decrease. And this has been proved by the well-borings. At Burford, where Hull expected no more than some 130 feet of Lias, the well-boring showed 598 feet.[2] So instead of the Rhætic beds being about 250 feet above sea-level, and consequently within about 100 feet of the surface at Signett near Burford, as Hull expected, they proved to be nearly 400 feet below sea-level.

[1] Mem. Geol. Surv. 1857, 'Geol. of Country around Cheltenham' p. 32.

[2] H. B. Woodward, 'Geology of England & Wales' 2nd ed. (1887) App. I facing p. 612: boring at Signett, about 1 mile south of Burford. See also Mem. Geol. Surv. 'Jurassic Rocks of Britain' vol. iv (1894) 'Lower Oolitic Rocks of England' p. 303.

Then the boring at Mickleton went through nearly 1000 feet of Lias; but I have not the details of it.

The difference between the thickness of the Lias at Burford and Mickleton is probably due to denudations of anticlinal elevations which occurred during Liassic times. If that surmise be correct, then there were many successive elevations along about the same axial lines, and many denudations; a deduction which is important. The decrease in thickness of Liassic rocks from Mickleton to Burford might be taken as a measure of estimated decrease farther on. But when such decrease is due to denudation, it is unsafe to do so, because directly the anticlinal fold is reached the rocks would begin to thicken again. That is where the difference lies between Hull's surmises and my results.[1]

(*f*) Bajocian Denudation and the Vale of Moreton.

A revised copy of the map of the Bajocian denudation, which appeared in the paper on the Cleeve Hill Plateau, may be given here (Pl. VI). I have marked therein the additional observations, made certain corrections, and put in the lines of the anticlinal and synclinal axes. The most important point is the alteration of the eastern lines of outcrop, showing that they run nearly with the eastern flank of the Cotteswolds, pointing to an anticline in the Vale of Moreton.

The coincidence of the axis of this anticline with the Vale of Moreton is certainly suggestive. It may be readily seen that the denudation would have had a considerable effect on the making of the Vale of Moreton, from two causes:—

(1) Owing to the anticline, an impervious bed is brought nearer to the surface along the line of the Vale of Moreton, thus favouring the outbreak of springs.

(2) Owing to denudation, something like 200 feet of what must have been a very protective limestone capping has been removed. The present denuding agencies get down to easily removed clay 200 feet sooner than they would have done without the Jurassic denudation.

The diagram given on p. 140 illustrates the aspect of affairs. It shows how, the Great Oolite being removed, there remained no protective covering of Inferior Oolite of any great thickness. So soon as that was cut through, the Lias would be easily excavated.

(*g*) Bajocian Denudation and the Vale of Bourton.

The peculiar shape of the Vale of Bourton has always seemed to be rather difficult of explanation. The Bajocian denudation seems to give the necessary clue. The Vale owes its existence to a combination of four circumstances; but without the Bajocian denudation

[1] [All the details given by Hull in his paper on the 'Attenuation of the Secondary Rocks' (Quart. Journ. Geol. Soc. vol. xvi, 1860, p. 63) agree with the idea of penecontemporaneous erosion, particularly of the successive erosions detailed here in Appendix II, p. 152.—*January 22nd*, 1901.]

it would not have had its peculiar shape. These four circumstances are:—

(1) The position of the River Windrush;
(2) The outcrop-line of the Great Oolite in the district, which normally, and if unaffected by faults, should run about from Turkdean to Icomb;
(3) The axis of the anticline of the Bajocian denudation; and
(4) Faults in the Stow district.

Of these circumstances, (1) the River Windrush would produce a valley directed south-eastward from Bourton, though it would not account for the extension of the Vale in the Slaughter district.

But such an extension is partly accounted for by the outcrop-line of the Great Oolite. Along the Fullers' Earth strike there would be a tendency to lateral widening of a valley. That tendency, however, would not be great if there were the normal mass of Inferior Oolite to be encountered, from where the Great Oolite had been removed. But then there was not. From where the Great Oolite had been removed there remained as a protective stratum only a thin band of Inferior Oolite, a few feet in thickness, due to the Bajocian denudation. That was easily broken through, and removed, when the soft clays of the Lias, which were at once encountered, favoured valley-formation.

The Vale of Bourton is, therefore, due

(i) To the normal cutting by the River Windrush;
(ii) To the removal of the Great Oolite by Tertiary denudation;
(iii) To the removal by Jurassic denudation of the main mass of Inferior-Oolite Limestone, which otherwise would have offered a thick protective covering.

Under such circumstances, then, the Vale of Bourton is quite normal, except that it is blocked northward by the high ground of Stow. Its western flank ought to extend in line with the eastern flank of the Cotteswolds by Bourton-on-the-Hill, Longborough, and Slaughter. It does not do this, on account of the faults in the Stow district. These faults let in the Great Oolite below the normal level, and thereby provided a thicker protective covering for the strata of the Stow district.

Thus the shape of the Vale of Bourton is seen to be dependent on the four circumstances mentioned, but especially on the Bajocian denudation. For, had there been in this vale 200 feet of Inferior Oolite to cut through, instead of only a few feet, then there would not have been the lateral expansion of the Vale. It would have had a character such as it possesses at Harford and Naunton—narrow and steep-sided.

(h) Penecontemporaneous Erosions and the Position of Coal.

There is something in this connection which may be considered, A Jurassic anticlinal axis runs about in the line of the Vale of Moreton. An anticlinal axis indicates a line of weakness. A line of weakness, once formed, tends to produce subsequent lines of weakness. Therefore the Jurassic line of weakness may indicate former lines of weakness; hence former anticlines; hence denudation.

There may, then, have been several elevations and several denudations on the same lines; so that the Palæozoic rocks may lie much nearer to the surface in the Vale of Moreton than has been supposed. It is known that during Liassic and Triassic times there were elevations and 'penecontemporaneous' erosions. If these also took place in the Moreton Valley, successively along the same line of weakness, were the Liassic and Triassic strata considerably reduced in thickness?

The subject of local erosion in the Lias has not been systematically followed up; with improved zonal work it may yield results as unexpected as those of the Bajocian denudation.

There is this to be noticed: the denudations have reduced the Inferior Oolite about four-fifths—from 250 to about 50 feet. Much less reduction than this in Lias and Trias would be most important. It is hardly to be expected that actual Coal-Measures would be found in the anticlinal axis; but they should lie along the sides thereof. In this direction studies of the Jurassic rocks may be of considerable economic importance.

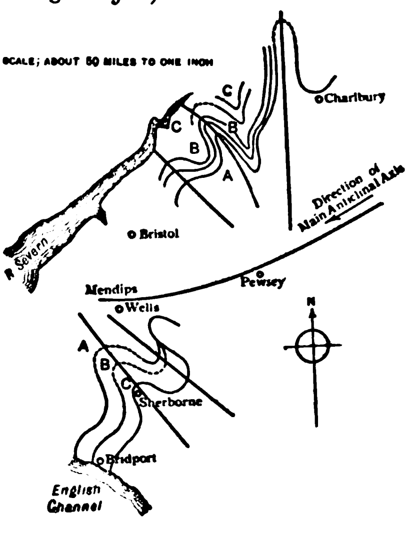
The relation of Jurassic folds to Palæozoic folds is suggested by these points:—

(1) That the Moreton anticline (Jurassic) is nearly in a line with the Pennine range; and
(2) That a main axis from the Mendips towards Pewsey is indicated by the folds of the Dorset and Cotteswold strata.

The anticlinal axes of the Cotteswold and Dorset strata are really lateral axes at right angles to a main axis; for the axes of the Cotteswold strata rise towards the south-east, but the axes of the Dorset strata rise towards the north-west. Across the Cotteswolds from the south-east higher and higher beds, but across the Dorset area from the south-east lower and lower beds, are found beneath the covering of the top beds of the Inferior Oolite. The appended diagram (fig. 4) is only a rough sketch, but it will illustrate the foregoing remarks.

The main axis runs from the Mendips north-eastward. At right angles more or less thereto are lateral axes.

Fig. 4.—*Diagram of the Cotteswold and Dorset strata, as they crop out beneath beds of* Garantianæ *hemera* (*Upper* Trigonia-*grit*).



The results seem to point to this:—That a force acting north-westward and south-eastward produced the main axis; that forces acting south-westward and north-eastward produced the lateral axes, even compressing the main axis so that the Mendips and a spot about the Pewsey Vale were elevated as the highest points, thus becoming foci of the lateral axes.

VI. Appendix I.

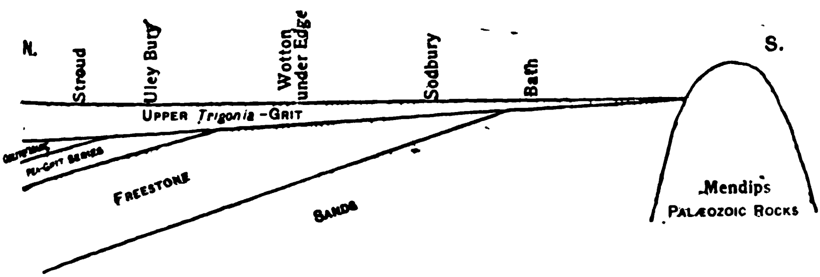
(a) The Position of the Upper *Trigonia*-grit.

To complete the information concerning the rocks upon which the Upper *Trigonia*-grit rests, in those portions of the Cotteswolds where there are no intervening beds, which have consequently not been dealt with in the series of papers mentioned on p. 138, the following notes may be made:—

Midford, near Bath: the Upper *Trigonia*-grit rests upon sands; *Struckmanni* hemera.
North Stoke, near Bath: upon sands; *Dumortieriæ* hemera.
Sodbury: upon Freestone, some 10 feet; *Murchisonæ* hemera.
Wotton-under-Edge: upon Freestone, some 25 feet; *Murchisonæ* hemera.
Uley Bury: upon strata of the Pea-grit Series and Freestone, some 60 feet; *Murchisonæ* hemera.

This is travelling from south to north for a distance of about 30 miles. The successively later date and the increase in thickness of the strata beneath the Upper *Trigonia*-grit should be noticed.

Fig. 5.—*Diagrammatic section from Stroud to the Mendips, showing the relation of the Upper* Trigonia-*grit to the underlying beds.*



The Mendips formed the anticlinal axis in this case; a rise in the Mendips (pre-Upper *Trigonia*-grit) produced the results illustrated above (fig. 5).

(*b*) Note on the Upper Freestone Series.

I may give here just an outline-section of what is perhaps the northernmost exposure in the Cotteswolds. It shows 25 feet of Freestone above undoubted Oolite-Marl. The Upton-Wold exposure (Section IX, p. 135) could hardly be a local alteration of this Freestone in that short distance; it is most likely a higher bed than any of the Freestone shown here. The following is the section:—

Hill above Chipping Campden.

				Ft.	ins.
Upper Freestone.	XI. White oolite			25	0
Oolite-Marl.	XII. Marly stone: *Rhynchonella subobsoleta* and *Terebratula submaxillata* 2 to 2½ feet down; *Terebratula fimbria* from 4½ to 9 feet down ...	Ft. 9	ins. 6		
	Stone band	1	10		
	Yellow clay	2	9		
	Stone	2	0		
				16	1
	Ironshot oolitic freestone			5	0

(*c*) Note on the Sandy Ferruginous Beds.

There is a section in these beds at Creddiford Brook (Wood Farm) near Guiting, on the road leading from Rowell Gate to Kineton—the old British road known as 'The White Way'—a west-and-east trackway from the Vale of Severn to the Vale of Moreton.

At Creddiford Brook are some 18 feet of a brown sandy stone, and in about the middle of the section a bed yielding somewhat plentifully, but not often perfect, specimens of *Rhynchonella subdecorata*.[1] It yields also lamellibranchiata, *Nerinæa*, etc.; so that it is quite a fossiliferous exposure.

The interest attaches to *Rhynchonella subdecorata*, which has been found, though sparingly, in this deposit in several places on the western flank of the Cotteswolds, accompanied sometimes by characteristic ammonites which enable the horizon to be identified on the one hand with the top of the Yeovil Sands (basal Inferior-Oolite beds of Dorset–Somerset) and with the Northampton Sands on the other.

Here in the North Cotteswolds, where the distinctive ammonites seem to fail, the *Rhynchonella* is sufficient; and it is also the same *Rhynchonella* that distinguishes certain basal 'Inferior-Oolite' beds at Hook Norton (Mr. E. A. Walford kindly sent me specimens

[1] The large form figured by Davidson, Monogr. Pal. Soc. 'Brit. Foss. Brachiop.' vol. i (1852) pl. xviii, fig. 10, & *ibid.* Appendix (1855) pl. A, figs. 23 & 25; not the small form of pl. A, figs. 24 & 26, which is another species, and occurs quite at another horizon.

TABLE II.

BURTON BRADSTOCK.	STOKE KNAP.	SOUTH SOMERSET.	MID-COTTESWOLDS.	NORTH COTTESWOLDS (WEST).	NORTH COTTESWOLDS (EAST).	OXFORDSHIRE.	NORTHAMPTON-SHIRE.
—	—	—	—		—	—	—
Lioceras spp.	*Aulacothyris Blakei.*	*Aulacothyris Blakei.*		*Aulacothyris Blakei.*	*Rhynchonella subdecorata.*		*Lioceras* spp.
Tmetoceras.	*Lioceras* spp.		*Tmetoceras.*	*Rhynchonella subdecorata.*		*Rhynchonella subdecorata.*	
			Rhynchonella subdecorata. *Lioceras* spp.				

of the species many years ago). So the Sandy Ferruginous Stone and its equivalents — the strata deposited during the *scissi* hemera —can be traced easily through five counties: Dorset, Somerset, Gloucestershire, Oxfordshire, and Northamptonshire. The beds are not continuous, because over certain areas they have been removed by 'penecontemporaneous erosion.'

On more than one occasion I have been asked to give information concerning methods of stratal correlation, particularly in cases where the species of identifying fossils vary with different localities. The strata of the *scissi* hemera seem to afford a good illustration of the manner in which, say, one of species G, H, may serve to identify a deposit which at a distant locality only yields species A, B. The appended Table (II) will be self-explanatory. The higher a species is placed in the column, the more common it may be considered at the locality in question.

(*d*) The Various 'Sands.'

What Hull calls and maps as Midford Sands (*g* 4) in the North Cotteswold area are really the sandy limestone-beds of the *scissi* hemera. They are distinctly later in date than what he maps under the same name in the Painswick district. These 'Sands' of the North Cotteswolds are really the westerly extension of the Northampton Sands of Northampton.

It may be advisable to tabulate here the different dates of the various 'Sands.' (See p. 152.)

TABLE III.—DATES OF THE VARIOUS 'SANDS.'

Northampton Sands & so-called 'Midford Sands' of the North Cotteswolds	*scissi* hemera.
Cotteswold Sands	*variabilis* & *Lilli* hemeræ.
Sands around Cole, Burton (Somerset)	*dispansi* hemera.
Sands near Yeovil	*Dumortieriæ* & *Moorei* hemeræ.
Sandy strata around Chinnock & Stoke Knap.	as late as *scissi* hemera.
Bridport Sands	late *Dumortieriæ* hemera to *opaliniformis* hemera.
Upper Lias Clay of Down Cliffs..................	early *Dumortieriæ* hemera.
Cotteswold Cephalopod-bed	*striatuli* hemera to *aalensis* hemera.

For reference I give the hemeræ in sequence from the latest to the earliest:—*scissi*, *opaliniformis*, *aalensis*, *Moorei*, *Dumortieriæ*, *dispansi*, *Struckmanni*, *striatuli*, *variabilis*, *Lilli*. The ammonite-succession which these names indicate is found regularly in this country, in Normandy where the strata are complete, and evidently, from Quenstedt's works, in Würtemberg.

The difference in the Sands mapped by Prof. Hull under the same name may be expressed in another way. According to the division of Lias and Inferior Oolite adopted by Oppel and other German geologists, the Sands of the North Cotteswolds are Inferior Oolite, those of the Mid-Cotteswolds Upper Lias. Or again, the Sands of the North Cotteswolds are of the Aalenian Stage, or Ludwigian Age; those of the Mid-Cotteswolds, of the Toarcian Stage, or Harpoceratan Age.[1]

VII. APPENDIX II.—DATES OF SOME EROSIONS IN 'JURASSIC' TIME.

(*a*) The Arietidan Epoch (Eojurassic Series).

Dates.	*Localities.*	*Notes.*
Pre-*armati* hemera.	Radstock.	Near the shore-line of the Mendips. Local erosion not uncommon at several other dates.
Pre-*ibex* „	Gloucestershire.	No *Jamesoni*-beds.
Pre-*spinati* „	Dorset coast; Dundry.	
Pre-*falciferi* „	Dorset coast; Dundry.	And perhaps more extensive.
Pre-*striatuli* „	Dorset coast; Dundry, etc.	The *bifrons*-beds being in a more or less remanié condition; the *Lilli* and *variabilis*-beds being absent.
	Cotteswolds.	Slight:—erosion of *variabilis*-beds, and pebbles.

[1] See 'Grouping of some Divisions of so-called Jurassic Time' Quart. Journ. Geol. Soc. vol. liv (1898) Table I.

Dates.	*Localities.*	*Notes.*
Pre-*Dumortieriæ* hemera.	Cotteswolds (Haresfield Beacon and northward.)	Possibly in Yorkshire, from fossil evidence. I do not know the strata.
Pre-*scissi* hemera.	Northamptonshire.	Very marked:—strata of eight hemeræ having been removed. Probably extends irregularly to the North Cotteswolds, but the erosion is not so marked.
In *Murchisonæ* hemera.	Cotteswolds (Randwick, Whittington, Horsepools, etc.)	Formation of pebbles, indicating penecontemporaneous destruction.
Pre-*discitæ* hemera.	Marked over the Cotteswolds, except perhaps over some of the North Cotteswolds. Dorset: Burton Bradstock & Chideock; Somerset: Bruton.	Erosion of the Upper Freestone marks this in many parts of the Cotteswolds. Its extension over the Dorset–Somerset district and in part over the Cotteswolds has been obliterated by the succeeding, more marked erosion. The absence of fossils of the hemeræ *concavi* and *discitæ* from much of the palæontological literature of the Continent probably indicates a considerable erosion of about this date on the Continent of Europe.
(*b*) Early Stepheoceratidan Epoch (beginning of the Neojurassic Series).		
Pre-*Garantianæ* hemera.	All over the Cotteswolds, Somerset, and nearly all Dorset, probably over most of England, and about the same date over Normandy.	Oborne and Clatcombe near Sherborne are the only places that I know in the South-west of England which are unaffected.

Such are the dates of a few penecontemporaneous erosions, and their extension over part of England. It will probably be found that they extended over many areas of the Continent. It may be pointed out, however, that to follow such extension carefully a system of minute zonal divisions is required, and that such a system depends on a correct limitation of ammonite-species.

VIII. Summary.

(1) The Bajocian denudation was brought about by slight
of the rocks due to small earth-movements, causing a ma
westerly to north-easterly axis of elevation, and s
north-westerly to south-easterly axes.

(2) Such removal of strata almost as soon as they h
deposited may be called 'penecontemporaneous erosion.'

(3) The chief feature of the North Cotteswolds is the dev
of strata between the Upper Freestone and the Lower T
grit: the strata being Harford Sands, a somewhat thick
fissile stone called the Tilestone, and Snowshill Clay.

(4) Another feature is the loss of the *Phillipsiana*-to-*Witch*
(inclusive) in the main-hill mass, owing to erosion.

(5) The Upper *Trigonia*-grit rests upon Notgrove Freeston
greater part of the area. The evidence that the Notgr
stone extended over the northern part of the district is i
for mapping the denudation.

(6) The Notgrove Freestone is, in the northern part of
distinguished by the abundance of *Pecten personatus* (?
the occasional occurrence of *Trigonia signata*.

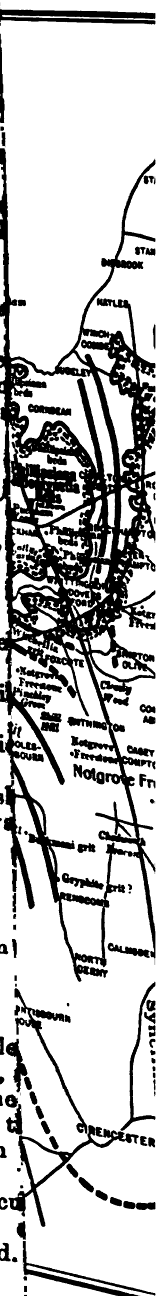
(7) Gryphite- and *Terebratula Buckmani*-grits are present,
exposed on the western flank.

(8) The Lower *Trigonia*-grit is considerably altered
character.

(9) The influence of penecontemporaneous erosion in th
of the Vales of Bourton and Moreton is considerable.

(10) Such erosion is likely to have taken place along simi
at different times, and therefore may be connected with
the Palæozoic rocks, and may have a bearing on the thi
the rocks overlying the Coal-Measures.

(11) The dates of various penecontemporaneous erosions s
during Jurassic times there were constant small elev
certain areas.



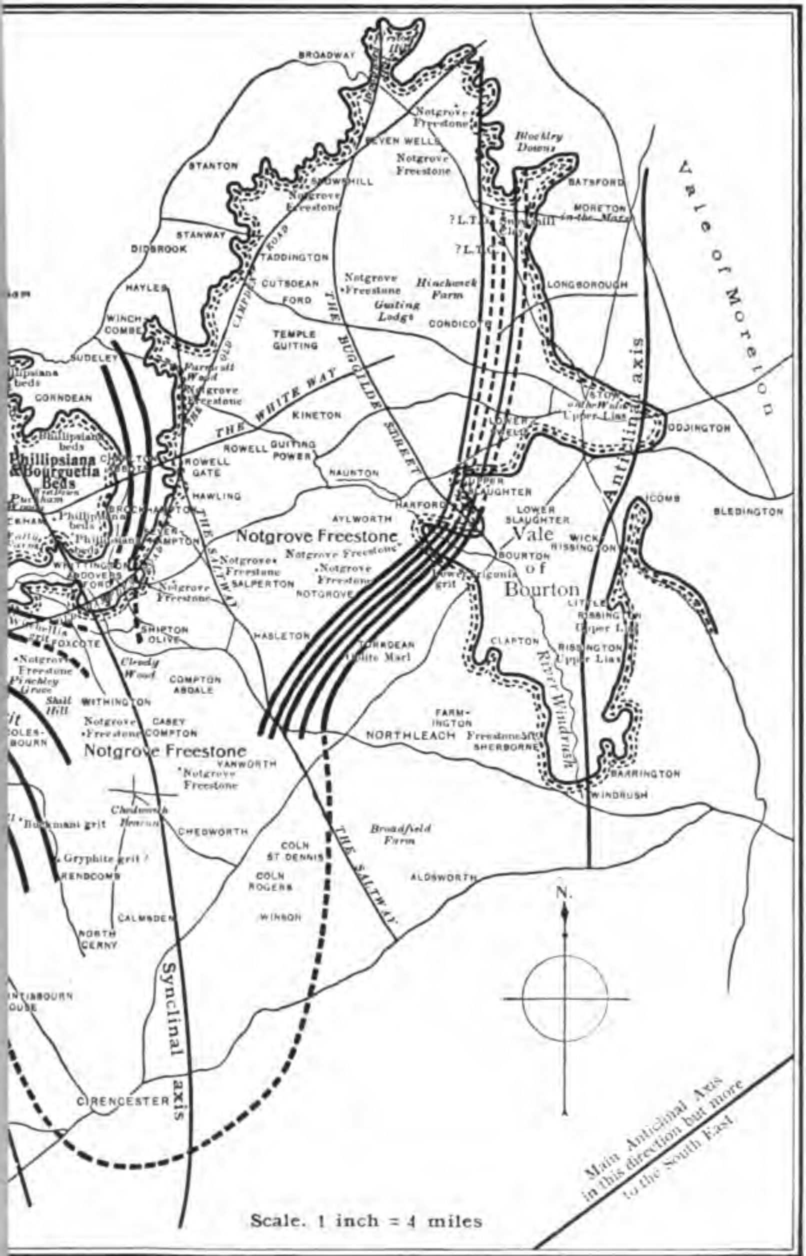
EXPLANATION OF PLATE VI.

Map of the Bajocian Denudation corrected to April, 1900; on
scale of 4 miles to the inch. (See p. 146.)

Discussion.

Prof. Groom complimented the Author on his valuabl
He had been over some of the ground with the Author,
sidered that a good case had been made out for a break in the
Oolite; but he thought that the relation of the upper to t
part of that series should be described by the simple term
formity.'

Mr. H. B. Woodward remarked that anyone who disc
Author's paper should follow rather than precede him
ground which he had so carefully and minutely described.



BROADWAY
STANTON
SNOWSHILL
STANWAY
DIDBROOK
TADDINGTON
HAYLES
CUTSDEAN
FORD
WINCHCOMBE
SUDELEY
TEMPLE GUITING
Notgrove Freestone
SEVEN WELLS
Blockley Downs
BATSFORD
MORETON in the Marsh
Vale of Moreton
LONGBOROUGH
CONDICOTE
Hinchcomb Farm
Guiting Lodge
THE BUGGILDE STREET
THE WHITE WAY
KINETON
CORNDEAN
Phillipsiana & Bourguetia Beds
ROWELL GATE
GUITING POWER
NAUNTON
HAWLING
ODDINGTON
Anticlinal axis
ICOMB
BLEDINGTON
UPPER SLAUGHTER
LOWER SLAUGHTER
HARFORD
AYLWORTH
Vale of Bourton
BOURTON
WICK RISSINGTON
SALPERTON
NOTGROVE
THE SALTWAY
SHIPTON OLIVE
FOXCOTE
HASLETON
TURKDEAN
CLAPTON
River Windrush
COMPTON ABDALE
WITHINGTON
CASEY COMPTON
FARMINGTON
NORTHLEACH
SHERBORNE
BARRINGTON
WINDRUSH
YANWORTH
CHEDWORTH
Broadfield Farm
COLN ST DENNIS
COLN ROGERS
ALDSWORTH
WINSON
RENDCOMB
CALMSDEN
NORTH CERNY
Synclinal axis
CIRENCESTER
N.
Main Anticlinal Axis in this direction but more to the South East
Scale. 1 inch = 4 miles

evidence of local erosion is indicated at various horizons in the Inferior Oolite by the occurrence of pebbles of oolite, etc., he thought that the local absence of fossil-beds like the *Trigonia*-grit or *Pholadomya*-grit was no more to be regarded as evidence of erosion, than the absence of the sands and tilestone and clay which locally formed part of the Inferior Oolite. The flexures suggested by the Author would, if drawn to scale, prove to be of very trifling dimensions.

Mr. Hudleston commented on the difficulty of basing an adequate discussion on the very short abstract of a long paper presented to the meeting at that late hour. He considered that in a previous paper the Author had established a fair case for what he should continue to call 'contemporaneous erosion' in the Inferior Oolite of Birdlip. There it was evident that beds had been removed previous to the deposition of higher beds of the same series.

From his intimate knowledge of the minor subdivisions of the Inferior Oolite, the Author possessed unusual facilities for detecting anything that was missing; and it would seem that in the present communication he had gone a step further, so as to indicate the undulations of the movement which had brought certain beds within the influence of denuding agencies. Such movements were undoubtedly on a very small scale, compared with those in the Shropshire Coal-Measures, to which reference had been made. He (the speaker) thought it possible that the great denuded anticline of the Vale of Moreton might be of later date than the Bajocian disturbances, but as the case was being tried without evidence he considered it safer to reserve his judgment.

Mr. E. A. Walford said that he doubted the evidence of the anticline along the Vale of Moreton. The tilt of the strata, he thought, was caused by the downslide of rock to the Vale in the usual manner.

Prof. Sollas and Prof. Watts also spoke.

10. *On the* Igneous Rocks associated *with the* Cambrian Beds *of the* Malvern Hills. By Prof. Theodore T. Groom, D.Sc., M.A., F.G.S. (Read December 19th, 1900.)

[Plate VII.]

Contents.

I. Historical Summary.

The crystalline core of the Malvern Hills was at first supposed by Horner [1] to be composed of igneous rocks intruded into the adjacent strata. Murchison at a later date imagined that the Hollybush Conglomerate and Hollybush Sandstone were submarine volcanic grits discharged from a fissure along which later the igneous mass of the Malverns burst through.[2] Phillips, however, adduced strong reasons for believing that the crystalline rocks had not been intruded into the Palæozoic strata [3]; he was, moreover, the first to recognize igneous rocks in the lowest portions of the latter. He described 'felspathic dykes' and 'interposed masses' in the Hollybush Sandstone; and 'porphyritic and greenstone-masses, which, erupted from below, have flowed in limited streams over the surface of the Black Shales.'[4] He pointed out that neither dykes nor bosses of trap occur in any of the strata above the Black (and Grey) Shales; though some of them, including those near Bronsil (numbered 108, 247, 248, & 249 in the present writer's map [5]), are situated in, or on, the upper part of the Shales. In the vertical section (p. 51) in Phillips's work, and in the horizontal section (No. 13) accompanying the memoir,[6] they are placed between

[1] Trans. Geol. Soc. ser. 1, vol. i (1811) p. 281.

[2] 'Silurian System' 1839, pp. 416, 418.

[3] Phil. Mag. vol. xxi (1842) p. 288, and Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) pp. 66 *et seqq.*

[4] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) pp. 52, 53, & 56.

[5] Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii.

[6] Reproduced in Sir A. Geikie's 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 170.

the Shales and the May Hill Sandstone. Phillips, with De la Beche, evidently believed that the igneous rocks were in part contemporaneous volcanic rocks, the outpouring of which, according to De la Beche, ceased with Llandeilo times.[1] Phillips, however, compares the igneous rocks of Tortworth with 'the greenstones of the lowest Caradoc Beds of Malvern,' remarking that the latter were 'effused on the sea-bed' during the 'early Caradoc' period.[2] Strickland imagined that the great movements which elevated the Malvern Chain and overturned the beds to the west were connected with this igneous action.[3] In 1862 and 1867 Timins[4] published chemical analyses of many of the igneous rocks associated with the Cambrian strata of the Malverns; and Holl in 1865 described them as a series of contemporaneous ashes, grits, and lavas.[5] In 1869 Symonds,[6] who had already[7] supported Murchison's views, and had, moreover, maintained that submarine volcanic action was responsible for the production of the trap in the Black Shales, and for the volcanic grits of the Hollybush Sandstone, spoke of pumice and scoriæ in the shales, and imagined the former existence of an island-volcano surrounded by deep sea. In 1874 the same author[8] referred to one of the igneous rocks (106 in the present writer's map[9]) as one of the outworks of a volcano the roots of which were situated in Raggedstone Hill. In 1884 he spoke of the Hollybush Sandstone as probably a consolidated mass of volcanic grit and ashes, erupted from a vent occupying the position of Raggedstone and Midsummer Hills, but he considered the traps of Fowlet Farm and White-Leaved Oak to be probably of later date than those interbedded with the Shales.[10] He further stated that the igneous rocks near Bronsil and Howler's Heath occupy the position which in North Wales is taken up by the Lower Silurian Beds (*op cit.* p. 42). In 1889 Symonds further maintained that the old lavas erupted through the Hollybush Sandstone and Black Shales occupy the position proper to the Llandeilo and Caradoc Beds.[11] Mr. Teall in 1888 recognized the presence of ophitic diabases in the Malvern Cambrians.[12] In 1898 Prof. Lapworth considered the majority of the igneous rocks associated with the Cambrian strata to be intrusive.[13] The present writer in 1899 and 1900 recognized in these igneous rocks a series of intrusive

[1] Mem. Geol. Surv. Gt. Brit. vol. i (1846) p. 38. The Malvern Black Shales were then regarded as of Llandeilo age.
[2] *Ibid.* vol. ii, pt. i (1848) pp. 194 & 195.
[3] Phil. Mag. ser. 4, vol. ii (1851) p. 359.
[4] Edinb. New Phil. Journ. ser. 2, vol. xv (1862) p. 1, and Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 352.
[5] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 87 *et seqq.*
[6] Trans. Woolhope N. F. Club, 1869, p. 6.
[7] 'Old Stones' 1st ed. (1855) pp. 31 & 43.
[8] Proc. Geol. Assoc. vol. iii (1874) p. 271.
[9] Quart. Journ. Geol. Soc vol. lv (1899) pl. xiii & p. 167.
[10] 'Old Stones' 2nd ed. (1884) pp. 25, 26, & 30.
[11] 'Flora of Herefordshire' 1889.
[12] 'British Petrography' 1888, p. 245.
[13] Proc. Geol. Assoc. vol. xv (1898) p. 338.

diabases and basalts,[1] and Prof. Watts[2] compared certain of the latter with 'diorites' associated with the Cambrian strata of other parts of Great Britain.

It will be seen from the foregoing summary that the igneous rocks in question have been, with few exceptions, regarded as due to contemporaneous volcanic action, supposed to have taken place either in Cambrian times or soon after.

II. Introduction.

The general distribution of the igneous rocks in the Cambrian strata of Malvern has been indicated in a former communication[3]; it will be sufficient, therefore, on the present occasion to point out that they occur at all horizons, and at all distances from the Archæan axis, though they are specially abundant at certain levels and in certain localities. They are found in the form of sills, small laccolites, bosses, or dykes. The preservation of the material leaves much to be desired, and it is only by having a large number of rocks sliced that it has been found possible to reduce the series to a few relatively constant types. I was formerly disposed to regard the more acid porphyritic members as amphibole-basalts (and andesites) of a peculiar type[4]; but a renewed investigation with the aid of further material has led me to doubt the propriety of these designations, and to regard the prevailing rocks of the district as ophitic olivine-diabases; olivine-basalts of somewhat unusual type; and amphibole-bearing porphyritic rocks of andesitic habit, but probably related, or belonging, to the camptonites.

III. Amphibole-bearing Rocks of Andesitic Habit.
(Pl. VII, figs. 5 & 6, & text-figs. 2, 5, pp. 161, 165.)

The igneous rocks prevailing in the Hollybush Sandstone are of a somewhat peculiar type. With two exceptions (M 236 & M 117*b*)[5] all the intrusive masses in the Sandstone belong to this type. Similar rocks also occur in both the Black and the Grey Cambrian Shales. The type is characterized by the presence of needles and stout prisms of a species of amphibole, often accompanied by phenocrysts of augite and felspar, and sometimes, perhaps, of ilmenite. These are set in a fine-grained andesitic groundmass, the felspar-laths of which very generally exhibit flow-structure. According to Timins's analyses (see Table IV, p. 176) the percentage of silica

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 131, 141, 158 *et seqq.*, 164 *et seqq.*, and Rep. British Assoc. 1900 (Bradford).

[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 169.

[3] *Ibid.* pp. 133, 138, 141, 157 *et seqq.*

[4] Rep. Brit. Assoc. 1900 (Bradford).

[5] Throughout this paper the numerals in parentheses preceded by M refer to numbers in the writer's map, Quart. Journ. Geol. Soc. vol. lv (1899) pl. xiii, and to numbered specimens in his collection.

generally appears to range from 51 to 58; the specific gravity, so far as determined, ranges usually from 2·58 to 2·67.

Some of the best-preserved examples are seen in the Hollybush Sandstone; the intrusions in this rock appear as dykes and small bosses. The distribution of these is shown in fig. 1 of the writer's paper on the Southern Malverns.[1] At the south-western corner of Midsummer Hill the presence of a number of small intrusive masses gives the ground a somewhat hummocky character. The relation of the dyke (M 112) to the Sandstone is shown in fig. 9 (p. 140) of the paper just quoted. At the north-western corner of Raggedstone Hill the main road cuts through another dyke of greater length, though it hardly extends so far as Holl stated.[2] Near its southern end is a small boss, and a portion of a second dyke: both of these would seem to invade not only the Hollybush Sandstone but also the Quartzite.[3] The Sandstone frequently seems to be much indurated and darkened in the neighbourhood of the long dyke, as Phillips evidently perceived.[4] This dyke is probably about 90 feet thick.

The material of these small intrusives is very uniform. It is compact, varies in colour from reddish-grey to dark greyish-blue, and shows small black-green phenocrysts. It weathers to a reddish or dark greenish-brown. The rock exposed is as a rule badly preserved, but sounder examples may be obtained here and there.

Under the microscope the freshest specimens (M 112 & M 439*a*) show a reddish, fine-grained pilotaxitic (or hyalopilitic) groundmass (Pl. VII, fig. 6, and text-fig. 2, p. 161), consisting largely of small, turbid, mostly untwinned laths of felspar (a n d e s i n e) showing flow-structure; numerous granules of a u g i t e; much scattered i l m e n i t e and t i t a n i f e r o u s m a g n e t i t e; a little a p a t i t e, as well as pale s e r p e n t i n e, t i t a n i t e, p y r i t e s, and other products of decomposition. The s e r p e n t i n e occurs in small irregular patches; but, owing to the altered condition of the rock, it is impossible to determine its source. Glass may have been present originally, but it is questionable whether any traces of it exist (see p. 161).

The phenocrysts include small reddish f e l s p a r s, both simple and twinned; small pale a u g i t e s; long or short needles, and short stout prisms of a m p h i b o l e; to these may be added ragged plates of i l m e n i t e, which appear to be original constituents. No traces of quartz, olivine, rhombic pyroxene, or of other phenocrysts can be detected.

Sections of other rocks (M 160*a* & M 243) intrusive in the Sandstone show an essentially similar constitution, but they are still more weathered, and the substance of the phenocrysts is often decomposed to such an extent that these are barely distinguishable

[1] Quart. Journ. Geol. Soc. vol. lv (1899) p. 132.
[2] *Ibid.* vol. xxi (1865) p. 88. [3] *Ibid.* vol. lv (1899) fig. 1, p. 132.
[4] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 53.

from the groundmass, the ingredients of which have suffered similarly.

Of the two varieties of the rock M 112, the specific gravity of the darker is 2·67, and that of the reddish variety 2·62. Timins's analyses (XIX & XX) of these two varieties gave as silica-percentages 52·12 and 56·03 respectively.[1] Two other analyses (XVII[2] & XX[3]), which probably belong to intrusives in the Sandstone, show 54·01 and 48·25 per cent. of silica respectively. If we may rely on these analyses, it follows that the chemical composition of the dykes includes both basic and sub-basic varieties.

Rocks essentially similar to those intrusive in the Hollybush Sandstone are associated with the Upper Cambrian Black and Grey Shales (M 101*a*, 104, 117, 125, 157*a*, 160, 183, & 209). They take the form of circular bosses, or of small laccolites or sheets intercalated in the Shales. All the larger bosses in the Shales belong to this series. The sills in the Black Shales have sometimes bleached the latter. Possibly the sills are in some cases connected with the circular bosses, but in no single instance is the exposure sufficient to show the relation of the bosses either to the sills or to the adjacent Shales.[4] The bosses possibly mark the position of the pipes which supplied the material for the sills and laccolites, or even for lavas poured out at the surface, and now removed by denudation.

Where best preserved, the material of these intrusive masses shows a purplish-grey (M 101*a*) or a bluish-grey coloration (M 104, 183, 209). More weathered examples (M 117) become greenish-grey, or dark-green (M 157*a*, 160*a*); and the most weathered assume a reddish-yellow (M 104), or an orange colour (M 160). The specific gravity of six of the rocks ranges from 2·58 to 2·67 (see Table I, p. 164).

Microscopically these rocks, for the most part, agree closely with their representatives in the Hollybush Sandstone (Pl. VII, fig. 5, and text-fig. 5, p. 165). The groundmass is nearly in an unaltered condition, the original minerals being invariably more or less decomposed, and replaced by serpentine, calcite, epidote, titanite, etc. The phenocrysts always include one or more of the following, or pseudomorphs after them:—amphibole, augite, felspar, and ilmenite (see Table I, p. 164).

In all the rocks described above, among the secondary products

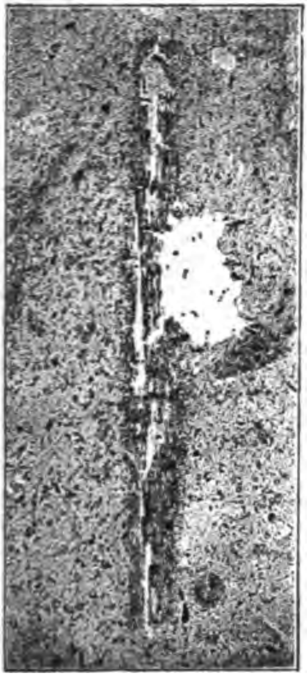
[1] Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 355. [2] *Loc. cit.*

[3] Edinb. New Phil. Journ. ser. 2, vol. xv (1862) p. 3. Other analyses in the two papers by this investigator are stated to relate to igneous rocks in the Hollybush Sandstone. Of these, No. XVIII. in the Quarterly Journal almost certainly refers to a rock in the Upper Cambrian Shales (see p. 176); No. XVI. in the same Journal may refer to a grey variety of the Hollybush Sandstone, or to the long dyke on Raggedstone Hill. No. XXI. in the Edinburgh Phil. Journ. possibly relates to the green Hollybush Sandstone itself.

[4] The Shales immediately north-west of M 183 [see Quart. Journ. Geol. Soc. vol. lv (1899) pl. xvii] dip beneath the straight side of the semicircular boss, but the actual junction is concealed.

Fig. 1.—*Cross-section of a completely-resorbed phenocryst of amphibole from camptonite (M 209), showing prisms and clinopinacoids.* × *110 diam.*

Fig. 2.—*Camptonite (M 439 a).* × *22 diam.*



A needle of colourless amphibole, showing the asbestiform condition. Sections of other needles (including a cross-section near the bottom of the figure) are visible. Most of the grey granules in the groundmass are augite; the black are iron-ore. In places the flow-arrangement of the minute felspar-laths is shown. The white patch is an imperfection in the section.

is a colourless substance, usually isotropic, or polarizing in weak tints, or occasionally more strongly, which occurs in irregular patches or small crystals in the groundmass, and sometimes in the phenocrysts. In the former case it often presents somewhat the appearance of a colourless glass. But apart from the improbability of a clear glass being present in greatly altered rocks of basic composition, the analogy of other rocks (see p. 171) makes it very probable that the substance is, at any rate in part, analcime.

A few details as to the character of the prevailing minerals may now be given.

The amphibole (Pl. VII, figs. 5 & 6; and text-figs. 1 & 2, also text-fig. 5, p. 165) occurs in two forms, both idiomorphic in the prism zone, with the prismatic faces well-developed and the clinopinacoids either large or small. The prevailing forms are short or long needles; less common are short stout prisms, apparently showing the shape of basaltic hornblende (Pl. VII, fig. 5) with terminal faces. These are generally larger than the needles, and are frequently corroded. They would appear to be undoubted phenocrysts.

The needles sometimes attain a considerable size (text-fig. 2), the largest seen measuring $\frac{3}{16}$ inch; but these are few in number, and the crystals are mostly small and not intricately corroded. It is difficult to say whether terminal faces are present or not. Two or three needles occasionally interpenetrate one another. The needles are usually very much

larger than the felspar-laths, and are often numerous (Pl. VII, fig. 6).

The outer border (and in many cases the whole crystal) has invariably been resorbed, with the production of grains of iron-ores, and probably of augite; and this renders the accurate measurement of angles a matter of impossibility. The faces of the prism meet at an angle of about 124°. When the substance of the crystal is preserved it is almost colourless, or of a very pale straw-tint, and accordingly shows no perceptible pleochroism. The substance is very fibrous, owing to the presence of two very close systems of cleavage parallel to the prisms, and intersecting at an angle of 124°. So close is the cleavage, indeed, that a relatively high magnification is required to detect it in cross-sections. A somewhat irregular jointing is seen in needles cut parallel to the vertical axis. The fibres are often of considerable length, and show strong refraction: they extinguish at an angle of about 18°. The amphiboles are evidently closely allied to, if not identical with, tremolite in the asbestiform condition.

Original tremolite in igneous rock is described by Becke in some of the Austrian serpentines.[1] Prof. Rosenbusch,[2] in speaking of the hornblende of diorites, says:—

> 'Relatively seldom the hornblende is of a very light green colour, and almost devoid of pleochroism: it assumes then the character of "strahlstein," and forms, not isolated crystals, but aggregates of needles.'

Prof. Barrois, indeed, speaking of a 'diorite' of this kind intrusive in the Cambrian of Lago in Asturias, says that the long prismatic and fibrous amphibole must be tremolite.[3] In view of the usual secondary nature of tremolite, it does not appear to be well-established in such cases that the original species was tremolite. Colourless hornblende is sometimes described as resulting from the bleaching of ordinary hornblende. Tremolite may arise from uralite, or from green reedy hornblende,[4] the latter itself being derived from ordinary green hornblende or from brown hornblende (*loc. cit.*). The Malvern tremolite might well be derived from a reedy form of amphibole. This appears to be borne out by a comparison with the amphibole of the Warwickshire 'diorites.' In these a colourless hornblende is described by Mr. Teall,[5] and in the rocks as seen in the Allport Collection, as well as in slides kindly lent to me by Prof. Lapworth and Prof. Watts, all stages may be found between crystals consisting of a brown reedy amphibole and others composed of a reedy or asbestiform, colourless tremolite.

The substance of the amphibole in the Malvern rocks is never

[1] Tscherm. Min. & Petr. Mitth. vol. iv (1882) pp. 338 *et seqq.*, 341 *et seqq.*, & 348 *et seqq.*

[2] 'Mikroskop. Physiogr. d. Massigen Gesteine' 3rd ed. (1896) p. 222.

[3] 'Recherches sur les Terrains Anciens des Asturies & de la Galice' Lille, 1882, p. 124.

[4] See Zirkel, 'Lehrbuch der Petrographie' 2nd ed. vol. i (1893) p. 304.

[5] 'British Petrography' 1888, p. 251.

perfectly fresh. Even in the best preserved examples, fibres of a substance with parallel extinction, indistinguishable from bastite, run in between and parallel to those of tremolite, together with fibrous serpentine (presumably derived from the bastite) similarly orientated. There is generally also some structureless serpentine. In most of the rocks the amphibole is nearly or quite replaced by bastite, serpentine, epidote, calcite, and other secondary products. Bastite is very generally regarded as derived only from the rhombic pyroxenes. But M. Boule[1] describes a case, analogous to the present one, in which all stages may be detected in the transition from tremolite to bastite in the serpentines of the Allier.

Fig. 3.—*A phenocryst of augite from camptonite (M 209).* × *72 diam.*

The phenocryst is traversed by serpentine (dotted), possibly pseudomorphic after intergrown hornblende. Granules of opacite have collected around the augite, an unusual phenomenon in the Malvern intrusives.

The augite-phenocrysts (text-fig. 3) are usually far less abundant than those of amphibole. They are of a very pale brown, show the usual form and cleavage, and have an extinction-angle of about 42°. The substance is better preserved than that of the amphibole. They may usually be distinguished at a glance from crystals of the latter, even when decomposed, by the absence of a resorbed border. They are sometimes honeycombed (see text-fig. 3) by spaces filled with serpentine (or bastite); but I suspect that in some of these cases the serpentine represents intergrown amphibole (see p. 164).

Fig. 4.—*Phenocryst of amphibole from camptonite (M 209).* × *72 diam.*

The above figure shows the resorbed border and intergrown augite, the eight portions of which (outlined in black) all extinguish together. Serpentine unshaded, faintly outlined; opacite (and leucoxene) black.

The augite of the groundmass is similar to that of the phenocrysts. It occurs in idiomorphic grains and crystals similar to, but less abundant than, those in the olivine-basalts. A number of granules are sometimes massed together into little accumulations, in the centre of which a serpentinous remnant of some ferro-magnesian mineral is occasionally seen (M 101*a* & 209).

[1] Bull. Soc. Géol. France, ser. 3, vol. xix (1891) p. 973.

Micrographic amphibole-augite phenocrysts.—In addition to the simple phenocrysts of amphibole and augite, there are a small number of tabular phenocrysts in at least two of the rocks (M 209 & M 101*a*) in which these two minerals are intergrown in an intimate manner. A pseudomorph after amphibole with a resorbed border may sometimes be seen to include a number of fragments of augite, all extinguishing together (text-fig. 4, p. 163, & text-fig. 5, below). The substance of the amphibole in these cases is replaced by bastite or serpentine. The bastite- and serpentine-

Fig. 5.—*A portion of M 101* a *(camptonite).* × 69 *diam.*

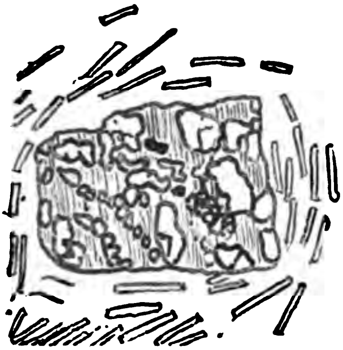
The above figure shows a corroded amphibole, with scattered grains of intergrown augite, all extinguishing together. Three or four of these are seen in the figure as dark patches in the lighter oval space on the right-hand side. Most of the granules in the groundmass are augite; the darkest represent iron-ore. The flow-arrangement of the felspar-laths is seen in the immediate vicinity of the phenocryst. [From a photograph.]

fibres run parallel to the vertical axis of the augite, whence it may be concluded that the two original minerals had this axis at least in common. In other cases which are apparently similar (fig. 6, p. 165, & fig. 7, p. 167), the augite is more abundant, and is penetrated by a meshwork of fibrous serpentine; and the resorbed border is incomplete or absent. It is only short, stout, forms of amphibole that appear to be intergrown with the augite, and apparently in the main those that have been corroded.

The felspar-phenocrysts are small, few in number, and

often of a reddish colour. They commonly give tabular sections, and not infrequently show zonal growth. They are simple, twinned once or several times. Rarely both albite- and pericline-lamellation are seen. Well-preserved crystals are not sufficiently numerous to permit of a determination of the angle of extinction, but the largest angle observed was 44°; others give quite small extinction-angles on the two sides of a plane of twinning. Probably more than one kind of felspar is present. Pseudomorphs containing calcite, serpentine, and opacite are not uncommon.

Fig. 6.—*Semidiagrammatic figure of a phenocryst from camptonite (M 209).* × *72 diam.*



The above figure shows augite intimately penetrated by fibrous serpentine, probably pseudomorphic after tremolite. [The fibrous character of the serpentine is exaggerated in the figure.] The different portions of augite (outlined in black) extinguish practically together. There is no resorbed border. The felspar-microlites show a flow-arrangement around the whole. See also fig. 7, p. 167.

The felspars of the groundmass are frequently reddish, and usually show lath-shaped sections. The extinction of the laths is usually undulatory; but they appear to belong for the most part to a basic andesine. They often show a tendency to split up into thin fibres.

The ilmenite-plates, which are of any size, are usually very ragged, and rarely show any trace of the six-sided form. This is seen, however, much more frequently in the small crystals of the groundmass, where they are mingled with octahedra of titaniferous magnetite, and with irregular grains of one or both minerals.

Apatite is present, both in the form of long needles and short prisms.

It is not easy to see where, in a classificatory system, the amphibole-bearing rocks described in the foregoing pages should be placed. By some petrologists they would doubtless be termed porphyrites or andesitic amphibole-basalts; but, as I am unacquainted with any basalts or other rocks agreeing precisely with them, I have thought it best to place them among the lamprophyres as andesitic camptonites, or as camptonites of the Malvern type.

TABLE I.—THE CHIEF ANDESITIC CAMPTONITES WHICH HAVE BEEN MICROSCOPICALLY EXAMINED.[1]

No.	*Locality.*	*Mode of Occurrence.*	*Colour.*	*Specific Gravity.*	*Percentage of Silica.*	*Phenocrysts definitely recognized.*
			HOLLYBUSH SANDSTONE.			
112	Hollybush.	Dyke.	Dark reddish-grey.	2·62	56·03	Amphibole, felspar.
112*	Hollybush.	Dyke.	Dark greyish-blue.	2·67	52·12	Amphibole, felspar.
160a	West of Midsummer Hill.	Boss.	Pink and dark-green.	2·62	......	Amphibole, felspar.
243	Raggedstone Hill, north.	Dyke.	Dark bluish-grey.	......	......	Amphibole, felspar.
439a	Raggedstone Hill, north.	Boss.	Reddish-grey.	......	......	Amphibole, felspar, augite.
			UPPER CAMBRIAN SHALES.			
101a	Near Martins.	Boss.	Purplish-grey.	2·67	......	Amphibole, felspar, augite.
104	North of Peudock's Grove.	Boss.	Bluish-grey.	2·66	57·64 (?)	Amphibole, felspar.
117	Chase End Hill, north.	Sill.	Greenish-grey.	2·58	......	Amphibole.
125	South of Fowlet Farm.	Boss.	Dark greenish-grey.	......	......	Amphibole.
157a	E.S.E. of Fowlet Farm.	Boss.	Dark green.	2·60	......	Amphibole, felspar.
160	West of Midsummer Hill.	Sill.	Orange-coloured.	......	56·12 (?)	Amphibole, felspar.
183	South of Coal Hill.	Laccolite (?)	Bluish-grey.	2·60	......	Amphibole.
209	West of Midsummer Hill.	Boss.	Greenish-grey.	2·66	......	Amphibole, felspar, augite.

[1] Altogether eighteen slices.

Fig. 7.—*Portion of a phenocryst, similar to that sketched in text-fig. 6, p. 165, but larger, lying at the edge of the same slide as that one. (× 25 diam.)*

Considerable corrosion has taken place, as seen in the upper part of the diagram, and in places there is a resorbed margin. In this semidiagrammatic figure the minerals are represented as in fig. 6; the black is opacite. The dark line at the bottom of the figure is a portion of the edge of the section.

IV. Augite-Basalt.

One rock (M 101), intrusive in the Grey Shales near Martins, differs both from the type just described, and from the olivine-basalts. It is compact, purplish-grey, and, like the preceding type, shows a fine-grained pilotaxitic (or hyalopilitic) groundmass, with numerous augite-microlites and granules, and some apatite. No amphibole is seen, and the only phenocrysts are numerous small, pale, partly or wholly serpentinized, augites. In its greater specific gravity (2·73), and probably in its lower percentage of silica and alkalies, and its greater percentage of iron, lime, and magnesia (see Table IV, p. 176), the rock differs from the andesitic camptonites, and approaches the olivine-basalts; but no olivine, or secondary biotite, is present. Serpentine and calcite, and probably analcime, occur among the alteration-products.

V. Olivine-Basalts. (Pl. VII, figs. 2–4.)

Associated with the Upper Cambrian Shales, and to a much smaller extent with the Hollybush Sandstone,[1] are a series of sills and small laccolites which belong to a type different from any of the rocks already described. No example of a dyke crossing the bedding is known to the writer. These rocks are widely distributed in the Shales, which in many instances they have bleached, or indurated, sometimes to a distance of several feet, though in other places the contact-effect has been slight. They differ from the andesitic amphibole-rocks in the nature of the groundmass; in the presence of phenocrysts of olivine (now invariably replaced by serpentine); and in the entire absence of phenocrysts of amphibole, augite, and felspar. They vary in thickness from 2 inches to 75 feet or more.

Their relation to the Shales can seldom be determined directly, except in the immediate neighbourhood of White-Leaved Oak. In the path leading from this village towards Fowlet Farm thin bands from 1 foot to several yards thick may be seen intercalated between the Black Shales. In the road leading south-westward from the village nearly vertical Black Shales with intercalated thin sills are seen; one of these sills, 2 feet in thickness, completely thins out in the course of a few yards. The Shales and thin sills are here underlain by a thick igneous mass (M 119). This appears to be a laccolite, for the Shales both above and below are parallel to its surface, and in spite of the considerable thickness (75 or 80 feet) it evidently thins out rapidly south-eastward, as may be inferred from the relief of the surface in that direction and from the absence of any thick sheet of basalt in the lane leading southward from the village: in this lane the succession of Black Shales is interrupted only by two thin sills of olivine-basalt. Thicker basaltic masses evidently set in again immediately east of the lane.

At the top of the lane, near the cottage on Chase End Hill, basalts at the base of the 'Middle Igneous Band' alternate with Grey Shales. One of the former is only 2 inches thick. The ground occupied by the main mass of the igneous band west of the lane rises up into more or less distinct oval elevations, as though concealing a number of inosculating laccolites. Many small lenticular sheets or laccolites are seen near Bronsil, where they form short wooded ridges. One of these (M 247), which is not less than 20 or 25 feet thick, is seen to be directly overlain by Grey Shales.

These basalts are of a fairly uniform type, both microscopically and macroscopically, but as the result of weathering they present very different appearances. In their freshest condition (M 117, 118, 175, 183, 214, 216, 218, 247, 249, 263, & 268) they are almost invariably compact, dark greyish-blue rocks, with small blackish-green phenocrysts. These latter are usually abundant, but become rare in some cases; and in others small phenocrysts, only to be

[1] Two of these rocks only (M 117*b* & 236) have been detected in it.

detected under the microscope, are alone present. Small rounded cavities filled with calcite, etc., which appear to be steam-vesicles, may be occasionally detected (M 231, 258, 269); but I have never seen the rock in the amygdaloidal condition mentioned by Phillips,[1] much less in the condition of 'pumice or scoriæ' described by Symonds.[2] Some of the rocks, even those of the freshest appearance (M 249), effervesce freely with acid. Surface-oxidation has almost invariably produced a thin brown crust; independently of this, the more exposed portions of the rock weather green, dark green, or brownish-green. Continued oxidation has produced in some cases a rusty brown or orange colour, but very frequently the gradual elimination of the green and red colouring-matter has caused the rock to assume a light greenish, brownish, or yellowish-grey colour. These greatly-weathered rocks often somewhat resemble sandstones, for which they appear to have been mistaken (p. 180). The phenocrysts at first showing black to the eye, under the influence of weathering lose their lustre, become dull green, then brown, and finally disappear, leaving small brown cavities, which have, I suspect, been regarded as vesicles. The rocks sometimes weather in a spheroidal manner.

The specific gravity in eight of the fresher examples (see Table II, p. 172) ranged from 2·61 to 2·82. A weathered example (M 117 *b*) gave 2·56.

Chemical analyses by Timins of three of the Bronsil masses (probably M 247, 249, & 108) gave as silica-percentages 42·42, 40·00, and 39·25.[3] Three analyses of two other basalts gave from 46·27 to 47·17 per cent. of silica; and in two doubtful cases the percentages were 41·85 and 43·53 (see Table IV, p. 176). The rocks would accordingly appear to be of thoroughly basic, or of ultra-basic, composition.

Microscopic examination shows that although the original condition is never retained, the prevailing types exhibit considerable uniformity in structure and mineralogical composition.

The only phenocrysts are pseudomorphs after an olivine poor in iron: these show the usual crystalline form, and are generally not corroded. The crystals often occur in groups (Pl. VII, figs. 2 & 3). The original olivine is now completely replaced by pale green, weakly-polarizing serpentine, calcite, and other secondary products. The serpentine often shows beautifully the characteristic mesh-structure, and is sometimes exquisitely spherulitic. The groundmass commonly shows a confused aggregate of lath-shaped felspars, iron-ores, and apatite, with serpentine, brown mica, calcite, epidote, titanite, and other secondary products. In the freshest examples (M 118, 214, 216, 218, & 268; Pl. VII, figs. 2 & 3, and text-fig. 8, p. 170) the original constitution can be fairly well made out.

[1] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 56.
[2] Trans. Woolhope N. F. Club, 1869, p. 6.
[3] These three analyses in any case refer with practical certainty to three of the four masses M 108, 247, 248, & 249.

In addition to the andesine felspar-laths, simple or twinned, and not uncommonly reddish along the borders, are small idiomorphic crystals and grains of a pale augite, with an extinction-angle of about 43° and good prismatic cleavage. These are often very abundant. The microlites are sometimes elongated, and lie parallel to the felspars. There is much scattered ilmenite and titaniferous magnetite, both in the form of irregular grains and small crystals. Long needles, or short prisms of apatite, are often enormously abundant, especially in the felspar; these are best seen in weathered examples (Pl. VII, fig. 4). There are also many scattered patches of clear isotropic serpentine, partly, and I believe largely, after augite. These patches in the more altered rocks are often impregnated with finely-divided calcite.

Some of the felspar-laths in the immediate vicinity of the serpentine-phenocrysts are almost invariably impregnated with serpentine, and in some of the more altered rocks, such as M 236,

Fig. 8.—*Olivine-basalt (M 118).*

Portion of the groundmass showing fibrous felspar-laths, iron-ores, augite-microlites (with refringent borders), and patches of serpentine (light in the figure). [From a photograph.]

the majority of the laths have been so affected, and give the impression of pseudomorphs after a ferromagnesian mineral.

In all the olivine-basalts there is a fair quantity of biotite, the fresh appearance of which at first sight seems to mark it out as an original constituent. In the fresher rocks, however, such as M 214, the mica is largely confined to the serpentine, and the size of the flakes is to a certain extent proportional to that of the patch of serpentine in which they lie; this mode of occurrence points definitely enough to the secondary, or rather to the tertiary, origin of the mica. The production of biotite has taken place most frequently in the

neighbourhood of the iron-ores, the grains of which it often fringes, or in ferruginous serpentine.

The groundmass, at any rate in the best-preserved rocks, is holocrystalline, and usually has an appreciably coarser texture than that of the amphibole-bearing rocks previously described. In this respect the groundmass approaches that of the more compact olivine-diabases of the district, but never shows the ophitic structure invariably seen in the latter. In some cases (M 102, 118, 119, 197, 248, 249, & 268) flow-structure is seen, but in the rest this structure is inconspicuous or absent.

Fig. 9.—*A pseudomorph, almost certainly after olivine, from an olivine-basalt (M 236).* × *45 diam.*

The centre is occupied by a large crystal of analcime (unshaded) embedded in calcite (dotted). The pseudomorph is lined with confluent crystals of analcime introduced from without. In the surrounding groundmass the precise structure is not clear, and the arrangement of plagioclase (lined), serpentinous pseudomorphs after augite (outlined in black), and opacite (black) is semidiagrammatic.

The order of crystallization has been: apatite and iron-ores; olivine-phenocrysts; augite; and finally, felspar.

Among the secondary products in the more altered basalts (M 117*b*, 236, etc.) is a colourless, sometimes rather cloudy, material which occurs in patches both in the groundmass and in the serpentinized olivines. It is frequently isotropic or nearly so, but at other times exhibits fairly strong double refraction. The patches often show a polysynthetic structure. Where distinct crystals are seen these almost invariably give six-sided sections (text-fig. 9, above). In one rock (M 236) such crystals are common in spaces which, for the most part, and I think in all cases, mark pseudomorphs after olivine. Where the crystals are large, they often show under polarized light the peculiar division into fields characteristic of analcime and garnet. The refractive index is low, and in spite of the somewhat strong double-refraction (which, however, is not unparalleled) there can be no doubt that the substance, in part at least, is secondary analcime. The analcime tends to line the wall of the pseudomorph, but merges gradually into the groundmass: sometimes one or more large crystals have grown into the middle, where they lie partly surrounded by calcite, or serpentine, or by both. The free faces of the small crystals are usually parallel to the side of the attachment (text-fig. 9, above). The occurrence of analcime in a pseudomorph after olivine is not usual; it has clearly been introduced from outside.

TABLE II.

OLIVINE-BASALTS WHICH HAVE BEEN MICROSCOPICALLY EXAMINED.[1]

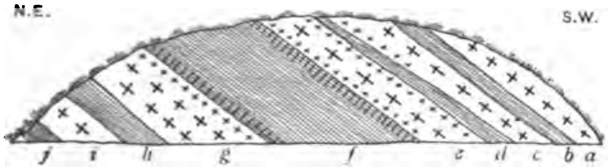
No.	Locality.	Probable Mode of Occurrence	Colour.	Specific Gravity.	Percentage of Silica.	Phenocrysts.
			HOLLYBUSH SANDSTONE.			
236	Raggedstone Hill, west.	Boss.	Dark greenish-grey.	2·70		Olivine only.
117b	Northern end of Chase End Hill.	Sill.	Brownish-green	2·56		
			UPPER CAMBRIAN SHALES.			
102	West of Pendock's Grove.	Laccolite.	Dark green.	2·66		
108	Near Bronsil.	Laccolite.	Dark bluish-grey.	2·73	39·25[2]	
117a	Chase End Hill, north.	Sill.	Light bluish-grey.			
118	South of White-Leaved Oak.	Sill.	Dark greyish-green.	2·75		
119	Roadside south-west of White-Leaved Oak.	Laccolite.	Dirty greenish-grey.			
197	West of Pendock's Grove.	Sill.	Dark greyish-green.			
214	North-west of White-Leaved Oak.	Sill.	Dark greyish-blue.	2·82		
216	Little south-west of 214.	Sill.	Greenish-blue.			
218	Western spur of Chase End Hill.	Sill.	Bluish-grey.			
247	North-east of Bronsil.	Laccolite.	Greyish-blue.	2·71	42·42	
248	North of Bronsil.	Laccolite.	Greenish-grey.	2·62		
249	North of Bronsil.	Laccolite.	Greyish-blue.	2·76	40·00	
263f, 263i, 263u	Immediately north-east of Coal Hill.	Laccolite.	Greyish-blue.	2·67, 2·61		
268	Small quarry, by cottage, south-west of White-Leaved Oak.	Laccolite.	Greyish-blue.			

VI. OPHITIC OLIVINE-DIABASES. (Pl. VII, fig. 1.)

With two doubtful exceptions (M 372 & 447) the diabases appear to be confined to the Coal-Hill band[3] of the Grey Shales. They occur as sills, and probably as small laccolites and bosses. The relation of the sills to the Grey Shales is admirably seen at Coal Hill Cottage (fig. 10, p. 173).

[1] Altogether twenty slices.
[2] This analysis may refer to No. 248.
[3] Quart. Journ. Geol. Soc. vol. lv (1899) p. 159.

Fig. 10.—*Section of Grey Shales and diabases at Coal Hill Cottage.*



Here five sills, *a*, *c*, *e*, *g*, and *i*, are intercalated in shales, as follows:—

M 182.	Thickness in feet and inches.		
a	1	6	Diabase (top not seen); sp. gr. = 2·71.
b		9	Indurated shale splitting into small rectangular blocks.
c .... $1\frac{1}{2}$ to	2	0	Diabase, rotten; fine-grained at the top; sp. gr. = 2·51.
d at bottom ...		9	Indurated shale, like *b*.
e	2	3	Diabase, fine-grained at the top and bottom; sp. gr. = 2·61.
f	5	0	Shales, baked yellow; top and bottom more baked than the middle; top very hard, hornstone-like.
g	3	6	Diabase, fine-grained at the top; sp. gr. = 2·69.
h	1	0	Shales.
i	2	5	Diabase.
j		10	Shales (bottom not seen).
	20	0	

The baking of the lower part of *f* proves the intrusive nature of the diabase. Outside the garden of the cottage higher rocks are seen, consisting of a thick sill of diabase overlain by thinner bands of shale and diabase. At the south-eastern end of Coal Hill a similar succession of diabases (M 184) and shales is seen. In the garden of the roadside cottage immediately south of Coal Hill the top of one diabase-sill not less than 6 feet thick, and the bottom of a second not less than 3 feet thick, are seen, separated by about 6 feet of Grey Shale. The beds (M 459) dip E. 30° N. at about 48°, and are presumably inverted like those on the road a little farther south. At this point (M 261),[1] marked in the writer's map by the dip-arrow 45°, three sills of diabase are seen, the middle one 1 foot thick, overlain and underlain by *Dictyonema*-bearing Grey Shales $2\frac{1}{2}$ feet and 14 inches thick respectively. The localities just mentioned are the only ones in which the relation of the diabases to the Shales is shown. Thicker masses than those mentioned occur; as, for instance, M 106, where a thickness of perhaps 15 or 20 feet is indicated. Holl also mentions a sill 35 feet thick in Coal Hill.

The diabases include coarse-grained (M 106, 182, 372, 459, etc.), medium-grained (M 182, 184, etc.), and fine-grained (M 182, etc.)

[1] See also Holl's section, Quart. Journ. Geol. Soc. vol. xxi (1865) p. 89.

types. Where freshest, the rocks are of a dark bluish colour; they often weather in a spheroidal manner,[1] the weathered portion assuming greenish, brownish, or yellowish colours. The medium-grained kinds, when weathered, often resemble ashy sandstones.

The specific gravity of the diabases investigated, with the exception of the rotten diabase M 182*c* (which has a specific gravity of 2·51), ranges from 2·61 to 2·75. The higher figure (M 106) is probably nearest to the original, for this rock is one of the freshest, most of the rest being considerably altered.

The percentage of silica in the specimens analysed by Timins[2] (M 106 & 182) ranges from 43·22 to 45·22. The rocks would then appear to be of thoroughly basic, or even of ultrabasic, composition. In all probability (see p. 179) the supposed ash-bands (IX, X, XI, & XII) of Timins (*loc. cit.*) are weathered diabases: the silica-percentage in these ranges from 35·12 to 48·00.

One of the freshest diabases in the district is M 106; Mr. Teall refers to this rock as a typical ophitic diabase.[3] M 372 is essentially similar. Under the microscope both these rocks are seen to consist of pale brown allotriomorphic augite, with an extinction-angle of about 41° and prismatic cleavages; pale green idiomorphic, hypidiomorphic, or allotriomorphic pseudomorphs after an olivine poor in iron, and now consisting chiefly of serpentine (with mesh-structure) and calcite; hexagonal corroded plates of ilmenite, now largely replaced by leucoxene; some apatite; and large laths of tolerably fresh or decomposed plagioclase, probably andesine: these latter are twinned once or many times. In M 106, brushes of long fibres, the microscopic characters of which are those of natrolite, have invaded the felspars; they are grouped in large fan-shaped or sheaf-like bundles. The apatite and iron-ores, the felspar, the olivine, and the augite have crystallized out in the order named. The felspar and olivine were the most abundant ingredients, the ilmenite the least. Octahedra of magnetite and secondary flakes of biotite are occasionally seen in the serpentine. In a more weathered but otherwise similar rock (M 182 *c*), the ferromagnesian minerals are altogether replaced by serpentine, calcite, etc. Varieties of fine grain (M 103, 184) show a similar constitution; in M 184 there is much calcite.

The marginal facies of a sill observed at Coal Hill Cottage (top of M 182*e*, Pl. VII, fig. 1) shows numerous large isolated lath-shaped and tabular crystals of clear felspar, mostly untwinned, but sometimes twinned several times; less abundant than these are serpentinous pseudomorphs apparently after olivine, sometimes penetrated by the felspar-laths, and masses of iron-pyrites. These are embedded in a very fine-grained groundmass of extremely minute laths of felspar, with small patches of serpentine, and many minute

[1] See also Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 56.

[2] Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 353, Nos. I (=M 182), and V, VI, & VII (= M 106).

[3] 'British Petrography' 1888, p. 245.

granular patches of sphene probably after ilmenite. The diabase at its margin thus acquires an andesitic texture. It differs from the olivine-bearing porphyritic rocks in several points, notably in the very fine character of the groundmass.

The diabases appear to have had a more marked contact-effect upon the shales than had the olivine-basalts. The Grey Shales are in many places baked yellow, or indurated into a rock resembling hornstone (see p. 173). Spotted indurated shale may be observed in débris near M 106. [For chemical analyses, see Table IV, p. 176.]

TABLE III.

OLIVINE-DIABASES WHICH HAVE BEEN MICROSCOPICALLY EXAMINED.

No.	*Locality.*	*Texture.*	*Specific gravity.*	*Percentage of Silica.*
103	South of Fowlet Farm.	Medium-grained; ophitic.	2·67	
106	On the road between Eastnor and Hollybush.	Coarse-grained; ophitic.	2·75	45·22 43·99 43·22
182 a, c, e, g	Coal Hill Cottage.	Coarse-grained to fine-grained; ophitic (to andesitic)	2·71 2·51 2·61 2·69	44·65
184	Southern end of Coal Hill.	Medium-grained; ophitic.	2·64	
372	Close to Fowlet Farm.	Coarse-grained; ophitic.		

VII. MUTUAL RELATIONS BETWEEN THE ROCKS DESCRIBED.

The porphyritic and the ophitic olivine-bearing rocks of the district are mutually related, both in chemical and mineralogical composition and distribution. In each group the chemical composition appears to range from thoroughly basic to ultrabasic, and the characters of the olivine and augite appear to have agreed in the two series. Both series are developed chiefly in the southern part of the district, but the diabases, unlike the porphyritic rocks, are chiefly confined to a particular horizon in the Grey Shales. The chief distinction lies in the generally coarser grain and the early appearance of the felspar in the diabases; these assume a porphyritic form only at the margin, and then the type produced differs from the ordinary olivine-basalts of the district. I have been able to detect no transitional types between the two series.

The amphibole-bearing rocks of andesitic type are quite distinct from the olivine-bearing rocks. They differ from the porphyritic members in their colour, chemical composition, and lower specific

Table IV.—Chemical Analyses by Timins relating to Igneous Rocks in the Malvern Cambrians.[1]

	Camptonites.							Augite-Basalt.	Olivine-Basalts.[2]							Olivine-Diabases.			
No. of Analysis.	XXI[3]	XVI[4]	XVIII[4]	XX[4]	XVII[4]	XIX[4]	XX[3]	XVIII[3]	VIII[4]	XVII[3]	XIV[4]	III[4]	XV[3]	XVI[3]	IX[4]	V[4]	I[4]	VI[4]	VII[4]
SiO_2	58·61	58·07	57·64	56·03	54·01	52·12	48·25	42·30	47·17	43·53	42·42	41·85	40·00	39·25	45·75	45·22	44·65	43·99	43·22
Al_2O_3	15·35	19·14	17·34	18·51	17·45	18·18	20·42	20·24	17·97	13·48	18·49	17·80	18·15	15·26	17·91	14·98	19·25	18·72	17·56
Fe_2O_3 & FeO	8·59	5·90	7·71	6·11	8·05	8·91	8·47	10·93	14·25	12·23	14·40	11·14	12·44	12·97	11·34	11·88	10·18	11·39	11·58
CuO	......	......	0·20	0·40	......	0·25	......	......	......	......	......	......	......	......	0·22	0·80	......	......	......
MnO............	1·75	0·25	0·15	......	......	0·20	1·00	0·75	0·50	1·75	......	......	1·50	1·50	0·58	......	......	......	......
CaO	2·31	1·95	2·42	2·39	2·36	2·52	3·85	3·20	1·92	10·22	9·96	8·17	6·70	6·97	2·05	6·73	4·28	5·05	6·14
MgO............	3·29	1·00	0·60	2·69	3·53	6·24	5·45	10·41	7·57	7·30	4·40	5·56	7·40	9·87	9·01	8·81	9·93	11·16	8·29
K_2O	0·15	11·73	10·34	11·39	11·65	6·78	2·60	3·08	7·55	4·26	3·31	8·03	4·47	5·15	7·18	5·39	5·87	3·61	7·39
Na_2O & loss	2·93						2·60												
Loss on ignition...	3·77	1·96	3·60	2·45	2·95	4·50	4·38	5·58	6·04	5·53	7·02	7·45	7·27	5·51	5·96	6·20	5·80	6·08	5·82
Loss at 212° F. ...	3·22	......	......	......	......	......	1·98	3·51	......	1·70	......	......	2·07	3·52	......	......	......	......	......
Locality of Rock	......	? Long dyke on Ragged-stone Hill.	M 104 ?	M 112	? Long dyke on Ragged-stone Hill.	M112*	? Long dyke on Ragged-stone Hill.	M 101 ?	From White-Leaved Oak igneous band.	(Possibly diabase.)	M 247	M 119 ?	M 249	M 248 or M 108	......	M 106	M 182 ?	M 106	M 106

[1] The author regrets that he is unable to furnish any new chemical analyses of these rocks, and those reprinted in this table are given in the absence of any more recent.
[2] Two analyses of one of the olivine-basalts (M 214) yielded to Mr. Cecil Duncan 46·55 and 46·27 per cent. of silica.
[3] Edinb. New Phil. Journ. ser. 2, vol. xv (1862) pp. 3 *et seqq.*
[4] Quart. Journ. Geol. Soc. vol. xxiii (1867) pp. 353, 355.

gravity; also in their structure, mineralogical composition, distribution, and to a certain extent in their mode of occurrence. While the olivine-bearing rocks are chiefly characteristic of the Upper Cambrian Shales, in which they take the form of sills and small laccolites, the amphibole-bearing rocks also invade extensively the Hollybush Sandstone, chiefly in the form of dykes and bosses; and even where the Upper Cambrian Shales are invaded the form assumed is often that of a boss. The groundmass is usually much finer grained than in the olivine-basalts, and flow-structure is invariably seen; the phenocrysts in the two series differ entirely, and secondary biotite, abundant in the basalts, is rare in the amphibole-bearing rocks. A fourth type of rock (augite-basalt) presents resemblances on the one hand to the 'andesitic camptonites,' and on the other to the olivine-basalts (see p. 167); but it is not intermediate between these types, for it contains neither amphibole nor olivine.

VIII. Comparison of the Malvern Intrusives with the Igneous Rocks of other Districts.

The Malvern diabases described in the foregoing pages in some respects resemble the olivine-diabases and dolerites which have invaded the Old Red Sandstone and Carboniferous rocks of Herefordshire, Worcestershire, the Clee Hills, the Forest of Wyre, and the Central English Midlands. Mr. Teall, however, points out that as a whole the olivine in these rocks is rich in iron, and that the augite is deeply coloured.[1] The Malvern diabases do not share these features. They differ from the Ordovician diabases of the Lake District, North Wales, and Shropshire in the presence of olivine, and in other respects.[2] They differ also from the Warwickshire ophitic 'diorites' in containing augite in place of hornblende.

Similar statements may be made with reference to the olivine-basalts. The Malvern examples belong to a somewhat unusual type, and differ from the usual Ordovician basalts of the Lake District and North Wales in the presence of olivine (Teall and Harker, *loc. cit.*). Olivine-basalts of Cambrian or slightly earlier age, and again of a different character, have been described by Sir Archibald Geikie from South Wales.[3] Olivine-basalts in the form of flows and dykes, more nearly allied to the Malvern basalts, abound in Scotland and Ireland, and occur to a more limited extent in the English Midlands[4]; but these newer rocks, where porphyritic, appear to differ for the most part in the greater variety of the phenocrysts.

[1] 'British Petrography' 1888, p. 214.

[2] *Ibid.* pp. 214 *et seqq.*; Harker, 'Petrology for Students' 1895, pp. 113 *et seqq.*; Watts, Proc. Geol. Assoc. vol. xiii (1894) p. 338.

[3] Quart. Journ. Geol Soc. vol. xxxix (1883) p. 304; see also Harker, *op. cit.* p. 175.

[4] Teall, 'British Petrography' 1888, pp. 186 *et seqq.*; and Harker, 'Petrology for Students' 1895, pp. 177–79.

The amphibole-bearing rocks of the Malvern Hills do not resemble the ordinary hornblende-basalts, andesites, or porphyrites. They appear to find their closest analogues in the Warwickshire 'diorites,' originally described by Samuel Allport.[1] The name camptonite has been suggested by Prof. Watts for these Warwickshire rocks.[2] He has kindly examined some of my slides, and considers that they conform to the Nuneaton type. Brief descriptions of some of the Warwickshire rocks have been published by Messrs. Teall,[3] Waller,[4] Rutley,[5] and Prof. Watts (*loc. cit.*). The last-mentioned has kindly sent me a number of slides belonging to Prof. Lapworth and himself; and, thanks to the courtesy of Mr. Teall and Mr. Prior, I have been able to examine many other slides of these rocks. One of the commonest types in the Warwickshire district has been figured by Mr. Teall.[6] This consists of idiomorphic needles of brown hornblende, with iron-ores and apatite, set in a holocrystalline coarse- or fine-grained matrix of more or less lath-shaped felspars. This type of rock perhaps corresponds most nearly with the Malvern amphibole-bearing series, but phenocrysts of augite are absent. Equally common is a type which differs from the foregoing in the presence of phenocrysts of olivine, which are often grouped together. These rocks seem to correspond with the Malvern olivine-basalts, but they possess amphibole instead of augite. One rock (554) from Dosthill, in the Allport Collection in the Natural History Museum, seems to connect the two Malvern porphyritic types: in a groundmass which much resembles that of these rocks, and of the augite-basalt (M 101), phenocrysts of olivine and augite are seen, but no amphibole.[7]

Taking the rocks as a whole, in spite of differences of development, there seems to be a considerable analogy between the rocks of the Malvern and Nuneaton areas. In both cases we have a series of small intrusive masses chiefly in the form of sills and dykes of more or less basic material which have invaded the Cambrian, but no later formations. Amphibole, augite, and olivine are characteristic minerals, and the amphibole was probably of the same peculiar character, and has undergone similar modifications in each case. There is, moreover, a marked tendency in both cases for the ferromagnesian minerals to give rise to serpentine rather than chlorite. In each district camptonitic features are developed in some of the rocks. This is seen in the complete absence of quartz, the rarity of phenocrysts of felspar, and the prevalence of the ferromagnesian minerals; among which biotite is absent in each case. Moreover, ophitic rocks, such as commonly are associated with camptonites, and which indeed are sometimes classed with them, are present in both areas.

[1] Quart. Journ. Geol. Soc. vol. xxxv (1879) p. 637.
[2] Proc. Geol. Assoc. vol. xv (1898) p. 394.
[3] 'British Petrography' 1888, pp. 250–51.
[4] Geol. Mag. 1886, p. 322. [5] *Ibid.* pp. 557 *et seqq.*
[6] 'British Petrography' 1888, pl. xxix, fig. 2.
[7] It is interesting to note that of all the localities in which Cambrian rocks are exposed in Warwickshire, Dosthill is the nearest to the Malverns.

Under these circumstances it seems permissible to suggest that we are dealing with an assemblage of rocks which have had a common origin. The most striking difference between the two districts consists in the greater abundance of hornblende in the Nuneaton area, and of augite in the Malvern district. In addition, a porphyritic character and flow-structure seem to be much more pronounced in the Malvern rocks. These three features give to the latter a more basaltic or andesitic habit. Some of the differences may be due to differences in chemical composition, but it seems possible that the Nuneaton rocks may have consolidated at a somewhat greater depth than did those of the Malvern area, and that the material which in the former crystallized out largely as hornblende, in the latter mostly took the form of augite. This hypothesis may, perhaps, account for the sharper separation of the different Malvern types; for differentiation may be supposed to have progressed with increasing distance from the more deeply-seated source.

According to this view the rocks may be contrasted as follows:—

Nuneaton.	Malvern.
1. Amphibole-camptonites devoid of olivine and augite.	1. Amphibole-camptonites and augite-basalt, both of andesitic habit, devoid of olivine, but with augite in the groundmass.
2. Olivine-camptonites with amphibole-needles.	2. Olivine-basalts, often andesitic, with augite-microlites in the groundmass.
3. Ophitic olivine-amphibole-diabases.	3. Ophitic olivine-diabases.

It should be observed that in some of the Nuneaton camptonites and diabases, augite is an important constituent; such rocks serve to connect the two districts.

Rocks of the Nuneaton type are not limited to the two districts compared. Prof. Watts records allied rocks in Shropshire,[1] and it is probable that certain rocks occurring in the Scottish Highlands, Anglesey, North Wales, and Charnwood, belong to the same category.[2]

IX. Supposed Pyroclastic Rocks.

Allusion has already been made to the fact that Murchison and Symonds regarded the Hollybush Sandstone as a volcanic grit (pp. 156 & 157). Phillips did not accept this view,[3] and I shall endeavour to show in a later communication that the Sandstone has not the least claim to this title and furnishes no evidence of contemporaneous volcanic action. Timins in 1867 analysed 'some thin beds, apparently formed by the deposition of felspathic ash.'[4] He

[1] Proc. Geol. Assoc. vol. xiii (1894) p. 336, & Quart. Journ. Geol. Soc. vol. lv (1899) p. 169.
[2] J. J. H. Teall, Geol. Mag. 1886, pp. 351 *et seqq.*
[3] 'Geology of Oxford & the Valley of the Thames' 1871, p. 66.
[4] Quart. Journ. Geol. Soc. vol. xxiii (1867) p. 356.

remarks that 'one of these may be observed on the east side of the quarry at the south-west base of Midsummer Hill'; he states, however, that the ash 'is, in part, of the structure of sandstone, and in part felspathic, with traces of epidote.' The analyses of this rock (XXIII & XXIV) show it to be of a decidedly more acid character than any of the igneous rocks associated with the Sandstone or with any of the Malvern Cambrians. I have nowhere been able to recognize in the Sandstone beds which resemble tuffs, and have examined what I believe to be the particular layer spoken of by Timins. It occurs along one of the joint-planes which run parallel to the surface of a dyke (M 112), and crosses the bedding, which is here very obscure. The supposed ashy layer appears to be nothing but a portion of the Sandstone, modified along a line of crushing and displacement.

After careful search in the Black and Grey Shales I have been equally unable to detect any traces of pyroclastic rocks. Crush-breccias are occasionally seen on a very small scale, and some of the rocks have somewhat the appearance of sandstones and fine tuffs. Indeed, Phillips speaks of sandstones interbedded with the shales,[1] and Holl describes ashes and grits in the 'Coal-Hill Band.'[2] Symonds also mentions volcanic grits in the Black Shales.[3] Microscopic examination shows that the supposed sandstones, grits, and ashes are nothing but weathered diabases and basalts (see pp. 169, 174).[4]

It must be concluded, then, that pyroclastic rocks are probably altogether absent from the Cambrian Beds of the Malvern area.

X. The Intrusive Character of the Rocks.

The camptonitic dykes and bosses in the Hollybush Sandstone must evidently be removed from the category of lavas, and so must the bosses in the Black and Grey Shales. There remain only the sheets and supposed laccolites intercalated in the Shales, and more rarely in the Sandstone. Of these the diabases, as might be expected from their general occurrence as dyke-rocks, are at least in part intrusive (p. 173). In the case of the basalts the question is more difficult; the materials are such as might belong either to a lava or to a small sill: the absence of glass, and the rarity and small size of the steam-vesicles rather support the idea of an intrusive origin. The basalts in many cases do not appear to have greatly affected the Shales, as was observed by Symonds (*loc. cit.*); but in other cases the Black Shales have been bleached in a somewhat sporadic manner, and

[1] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 54.
[2] Quart. Journ. Geol. Soc. vol. xxi (1865) pp. 89 & 90.
[3] 'Records of the Rocks' 1872, p. 73.
[4] It may be pointed out here that, although the grits described by previous observers appear to be non-existent, a series which could hardly have been seen by them has been detected by the writer, but these are in no way pyroclastic: see Rep. Brit. Assoc. 1900 (Bradford).

in a certain number of instances the basalt has bleached, not only the Shales below, but also those above, a circumstance which proves that at least some of the sheets are sills. But perhaps the strongest piece of evidence for the intrusive nature of the basalt-sheets is the complete absence of tuffs or, indeed, of pyroclastic materials in the Cambrian sediments. The available evidence points, then, to Prof. Lapworth's conclusion that of the igneous rocks in question 'the majority are certainly intrusive' (see p. 157). We may note, as in agreement with this conclusion, that the igneous rocks associated with the Cambrian of other parts of the Midland district are intrusive, and that, as pointed out to me by Prof. Watts, Cambrian volcanic rocks nearer than South Wales are not known.

XI. Date of Intrusion.

The rocks described in the foregoing pages have apparently shared the foldings and dislocations which affected all the older rocks of the Malvern district. I maintained on a former occasion[1] that these movements dated principally from Coal-Measure times. The olivine-diabases which have invaded the Carboniferous of the English Midlands possibly date in part from this period, for they seem to have invaded the Lower and Middle Coal-Measures, but not the Upper. The igneous rocks intrusive in the Malvern Cambrians bear the stamp of greater antiquity. Rocks which, to the eye seem fresh and unweathered, show under the microscope considerable physical and chemical changes. The olivine-diabases are never so well preserved as the very similar Carboniferous diabases. The felspars of these and the olivine-basalts so commonly show undulatory polarization that the determination of the species is generally a matter of difficulty. The olivine is invariably serpentinized, and the serpentine has given rise to tertiary minerals such as biotite.[2] If it be granted that the olivine-diabases and basalts and the andesitic camptonites are intrusive, it follows that the intrusion took place, at any rate in part, in late Tremadoc or in post-Tremadoc times, for all three types invade the uppermost Tremadoc Shales seen. On the other hand, as Phillips pointed out, the igneous rocks do not invade the May Hill Sandstone.[3] It follows, therefore, with high probability that injection took place in Ordovician times, or at least not before the deposition of the uppermost Tremadoc Beds, and not later than that of the lowest May Hill Beds in the district. This is in agreement with the fact that the allied rocks of other districts are not known to invade any rocks later than the Cambrian.

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 175 *et seqq.*

[2] It must be noted, however, that the imperfect preservation of the Malvern rocks is doubtless due in part to the absence of deep or recently-worked quarries.

[3] Mem. Geol. Surv. Gt. Brit. vol. ii, pt. i (1848) p. 57.

XII. Relation of the Igneous Rocks described to those of the Archæan Massif.

Seeing that the intrusive rocks which have invaded the Cambrian strata must have passed through the underlying Archæan, it might be expected that representatives of them would be found in the neighbouring Archæan complex, and that the latter should, therefore, contain not only pre-Cambrian but also later igneous masses. The circumstance that the three chief types of rock—namely, diorite, granite, and felsite, which according to Dr. Callaway[1] enter into the composition of the Malvernian complex, have undergone an apparently pre-Cambrian foliation, militates against the idea that either the granite or the coarser diorite can be the plutonic representative of any rock seen in the Cambrian strata. It is, however, conceivable that certain of the rocks regarded as diorite may belong to the same series as the hornblende-rocks in the Cambrian Beds; but, until the diorites of the Malvern chain are better known, it will be impossible to deal with this question. Augite-bearing rocks appear to be rare in the Malvernian. Proterobases and epidiorites are described by Mr. Teall,[2] but rocks of this description do not invade the Cambrian. The same writer, however, detected among the rocks on Swinyard Hill an ophitic diabase precisely similar to those seen in the Cambrian.[3]

Augite-bearing rocks occur in the Warren House (Uriconian) Series,[4] but from Mr. Rutley's descriptions and from a personal examination of Mr. H. D. Acland's slides by the present writer, it appears that these rocks are of a type different from any seen in the Cambrian.

We have, then, no certain proof that, with the exception of the olivine-diabase, any of the rocks described in the foregoing pages have invaded the Archæan. Prof. Watts informs me that this is also the case with the allied intrusive rocks of other parts of the English Midlands.

XIII. Conclusions.

The Cambrian of the Southern Malverns is associated with a series of igneous rocks which have commonly been regarded as volcanic. There are, however, among them no truly vesicular rocks and no tuffs such as have been mistakenly described, and the rocks are probably all intrusive.

Petrographically the assemblage may be divided into three, structurally and mineralogically very constant, types, and a fourth

[1] Quart. Journ. Geol. Soc. vol. xliii (1887) pp. 526 & 527.

[2] 'British Petrography' 1888, p. 245.

[3] *Loc. cit.* The rock (1140) to which reference is made may be seen in the Natural History Museum: it contains abundant serpentinized olivine.

[4] F. Rutley, Quart. Journ. Geol. Soc. vol. xliii (1887) pp. 497–99, and H. D. Acland, *ibid.* vol. liv (1898) pp. 559 & 561.

Fig. 1, X 72.

Fig. 2, X 15.

Fig. 3, X 33.

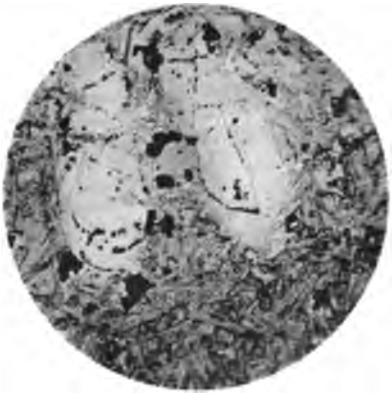


Fig. 4, X 67.

Fig. 5, X 10.

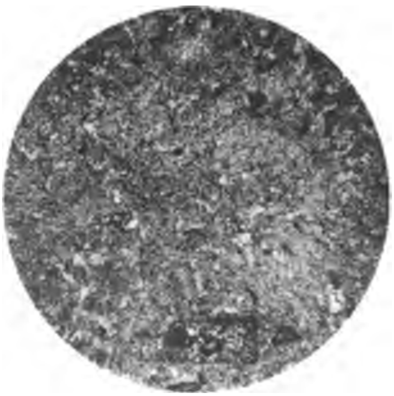


Fig. 6, X 16.

T. T. Groom, Photo-micro.

Bemrose, Collo., Derby.

Igneous Rocks from the Cambrian of the Malvern Hills.

subordinate type. To these belong a series of ophitic olivine-diabases; a related series of porphyritic olivine-basalts; and a series of amphibole-bearing porphyritic rocks, probably to be regarded as camptonites. These types are not connected by intermediate gradations; all three show a different distribution; and the olivine-bearing and the amphibole-bearing rocks have a different mode of occurrence. According to existing analyses the former range in chemical composition from thoroughly basic to ultrabasic; the latter are generally more acid, and include sub-basic varieties.

The rocks appear to find their nearest analogues in the camptonitic 'diorites' of Warwickshire and other parts of the British Islands, and like these occur only in association with Cambrian rocks; but the whole assemblage has the stamp of a local character. The Warwickshire rocks, to a certain extent, appear to bridge over the gap which exists between the Malvern Amphibole-bearing Series and the Olivine-bearing Series.

Intrusion took place in times later than the deposition of the Tremadoc Beds of the Malvern district, and probably earlier than that of the Upper May Hill Sandstone.

In conclusion I would express my sincere thanks to Prof. Watts and Prof. Sollas, who have given me the benefit of their opinions on some of the more obscure rocks. To Mr. Cecil Duncan I am indebted for the determination of the percentage of silica in one of the rocks; to Prof. G. Paton for kind assistance in photographing some of the rocks; to Mr. G. T. Prior for references to the literature of the subject, and much courtesy shown to me during my examination of the rocks in the Allport Collection; and to Mr. H. D. Acland for the kind loan of rock-sections.

EXPLANATION OF PLATE VII.

Fig. 1. Portion of the marginal facies of olivine-diabase (M 182e), showing small phenocrysts of felspar in a groundmass containing minute laths of felspar, etc. × 72.

2. Olivine-basalt (M 214), showing a group of phenocrysts of serpentinized olivine in a groundmass of felspar-laths, augite, ilmenite, etc. × 15.

3. Olivine-basalt (M 214) with a small group of phenocrysts (after olivine), in a groundmass showing clearly the augite- and felspar-microlites and iron-ores. × 33.

4. Olivine-basalt (M 249). Portion of the groundmass showing felspar-laths, some very fibrous; needles of apatite; iron-ores; and patches of serpentine, probably after augite. × 67.

5. Andesitic camptonite (M 101*a*), showing dark bastite-and-serpentine-pseudomorphs after amphibole, set in a fine-grained groundmass. Most of the small dark patches seen are sections of needles of amphibole, but a stout phenocryst is shown at the bottom of the figure. × 10.

6. Andesitic camptonite (M 439*a*), showing long and sometimes interpenetrating crystals of nearly colourless amphibole, with a resorbed border. × 16.

Discussion.

Mr. Prior congratulated the Author on obtaining such interesting results from what at first sight appeared to be very unpromising material. As regarded the 'camptonitic group' he felt some doubts concerning the nomenclature. In the case of many of the Nuneaton rocks the name camptonite appeared to be justified; but the Malvern rocks, in their structure and in the character of the hornblende, seemed to be more closely related to hornblende-basalts than to typical camptonites.

Prof. Watts pointed out that Allport had indicated that the Warwickshire 'diorites' were a group of rocks distinct from the dolerites of the Midlands. Similar rocks had since been found associated with Cambrian strata in a variety of districts. In the Nuneaton region the camptonites were not associated with olivine-dolerites or diabases, and it was difficult to say to what this type of rock in the Malvern area was related.

Dr. J. W. Evans referred to the fact that a similar association of calcite and analcime had been described by Glocker from the Moravian teschenites in 1852. With regard to the use of the term camptonite, he had always understood that it denoted a subdivision of the mica-trap or lamprophyre-group, and, therefore, implied a predominance of ferromagnesian silicates.

The President and Mr. Cunningham-Craig also spoke.

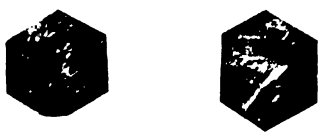
The Author said, in reply to the President and to Mr. Prior, that he did not think the amphibole-bearing rocks described greatly resembled the vogesites or the typical hornblende-basalts. They appeared to be more acid than the latter, and the abundant felspar of the groundmass was chiefly or wholly plagioclase. Some of the amphiboles might be the small representatives of the large corroded phenocrysts of the hornblende-basalts, but most of them showed the needle-like form so common in the lamprophyres; though, as Mr. Prior had pointed out, a resorption-border was always present. It was doubtful whether more than one generation of amphibole was present or not, and the rocks appeared scarcely to conform to the strict definition of camptonite as given by Prof. Rosenbusch; and it was with some hesitation that the Author had regarded them as peculiar members of this group, rather than as forming a new type. In reply to Dr. Evans, the Author said that he had not thought it well to place too much reliance on the chemical analyses given, as they had been made many years ago. While recognizing the differences mentioned by Prof. Watts between the olivine-bearing rocks of Malvern and Nuneaton, the Author said that olivine-augite-rocks, apparently devoid of hornblende, one of which approached the Malvern olivine-basalts in several respects, occurred at Dosthill, though still undescribed. He could give no satisfactory answer to Mr. Cunningham-Craig's question as to the order of intrusion of the different types described, since in no case known to the Author were two rocks of different type seen in mutual contact.

11. NOTE *on the* OCCURRENCE *of* CORUNDUM *as a* CONTACT-MINERAL *at* PONT PAUL *near* MORLAIX (FINISTÈRE). By A. K. COOMÁRA-SWÁMY, Esq., B.Sc., F.L.S., F.G.S. (Read January 9th, 1901.)

IN the neighbourhood of Morlaix the schists and quartzites of the Lower Devonian are extensively developed. They are much altered, and often injected by intrusive granite. The altered rocks are described by Prof. Barrois[1] as quartzites micacés and leptynolithes. The minerals found in the latter include biotite, muscovite, andalusite, sillimanite, quartz, iron-oxide, chlorite, garnet, staurolite, zircon, graphite, and rarely felspar. The quartzites micacés contain large grains of irregular quartz (not clastic), with flakes of dark and white mica, zircon, iron-oxide, graphite, and garnet.

Among the intrusive masses, that of Pont Paul is of especial interest. The rock is a granite rather poor in quartz; the minerals include orthoclase, microcline, oligoclase, quartz, hornblende, biotite, apatite, zircon, sphene, and allanite[2] (the last two not noticed by myself). The granite is much decayed for a depth of many feet. Included fragments of dark micaceous rocks are to be found in it: they are about the size of a man's fist, and not very abundant. Some may be found *in situ*, and dug out of the crumbling granite, others by searching the floor of the shallow quarry. These included fragments resemble the Devonian leptynolithes of the district. They contain abundantly small tabular hexagonal crystals of blue corundum, first noticed by Prof. Barrois in 1887.

Fig. 1.—*Isolated crystals of corundum (washed in hydrofluoric acid). See p. 186.*



[Striations on the basal plane are faintly indicated. From a photograph: × about 9.]

Examination of thin sections of the included fragments shows that the minerals certainly present are biotite, muscovite, corundum, plagioclase, andalusite, pyrite, magnetite, sillimanite, green spinel, and zircon. Orthoclase and quartz may possibly occur.

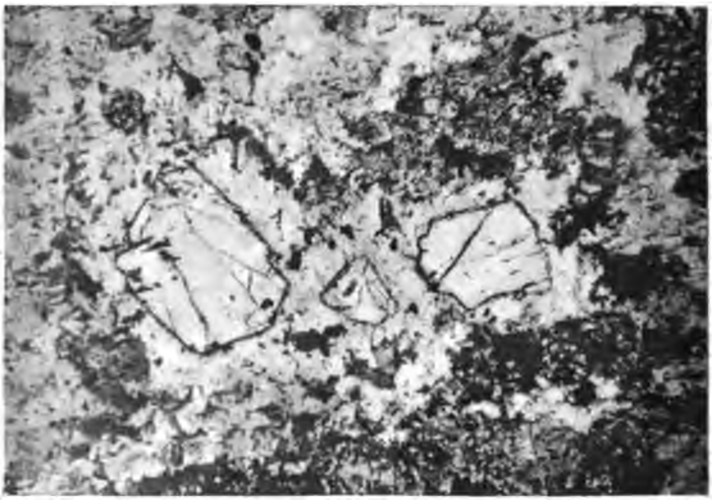
The corundum is very abundant, forming conspicuous crystals which exhibit hexagonal or rectangular outlines, and contain comparatively few inclusions of iron-oxide, very much more rarely sillimanite and zircon, also gas-inclusions. The crystals in a thin section are colourless, or have a faint blue tinge, unequally distributed. In the latter case there is slight pleochroism from pale blue for the ordinary ray, to very pale greenish-yellow for the extraordinary. Optical anomalies were not observed. Cleavage parallel

[1] Bull. Soc. Géol. France, ser. 3, vol. xiv (1887) p. 890.
[2] Michel Lévy & Lacroix, 'Note sur un Gisement français d'Allanite' Bull. Soc. Min. France, vol. xi (1888) p. 65.

to r (10$\bar{1}$1) is not infrequent; the cleavage-cracks become more conspicuous in polarized light, as is often the case with calcite. Traces of a parting parallel to c (0001) are also sometimes seen. The rock appears a little bleached in the neighbourhood of the corundum, that is, colourless minerals rather than mica are usually in contact with it; but this is not invariably the case. Less pure corundum occurs also in a finely granular form, mixed with other minerals from which it has not, as it were, been able to free itself.

Isolated crystals, detached from the matrix, and washed in hot hydrofluoric acid, are tabular in form, being combinations of the hexagonal prism and basal plane, the latter characteristically striated

Fig. 2.—*Three individuals of corundum seen in a thin section of one of the included fragments.*



[On the left hand is one with hexagonal outline, cut approximately parallel with the basal plane. A zone of lighter coloured minerals separates the three crystals from the darker part of the rock. From a photograph: × 27·5.]

(see fig. 1, p. 185) and sometimes slightly stepped. One of the largest measured about 1·7 mm. in greatest diameter by ·5 mm. in thickness, and weighed about ·005 gramme. The crystals have a beautiful sapphire-blue colour.

The dark mica is strongly pleochroic, from warm dark-brown to pale straw-colour.

Andalusite is fairly common, occasionally showing faint characteristic pleochroism, or nearly rectangular cleavage with diagonal extinction. The greater part is, however, ill-defined, and not easy to distinguish.

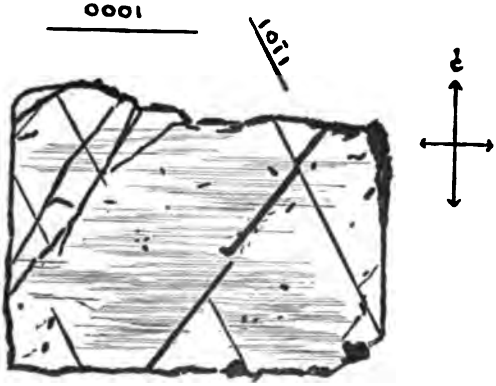
A minute mosaic of colourless grains, with low refractive index and weak interference-colours, fills up the background; and in many cases these show the multiple twinning of plagioclase. Twinning on the albite and pericline plans is found: in one case also, apparently Carlsbad twinning occurred. Among others, the following nearly symmetrical extinction-angles were measured from (presumably) albite twin-lamellæ:—12·11, 12½·13.

Some few individuals which appear untwinned, and extinguish approximately parallel to their greatest length, may be orthoclase.

It is difficult to be certain about the occurrence of quartz. I feel sure, however, that very little or none is present, for close examination of many tiny grains in the colourless mosaic which suggested possible quartz, revealed faint multiple twinning, or a portion of a biaxial interference-figure was obtained. The numerous inclusions of the colourless minerals render their examination somewhat troublesome.

Iron-ore is abundant in scattered grains, and also as inclusions in the other minerals, including corundum.

Fig. 3.—*Individual of corundum seen in a thin section of one of the included fragments.*



[The crystal is cut at right angles to the basal plane, which is slightly stepped owing to alternation with a rhombohedral face. The faint horizontal shading indicates approximately the distribution of the pale blue colour. The sharp rhombohedral cleavage-cracks are drawn, as if seen between crossed nicols; in ordinary light they are o ly with difficulty distinguishable. The few inclusions consist of iron-ore, a little sillimanite, a grain or two of zircon (?), and gas-inclusions. × 38·6.]

Sillimanite is locally abundant, elsewhere scarce or perhaps absent. Where abundant, it forms sheaves and aggregates of much elongated colourless crystals. The characteristic transverse parting is seen, the segments being often separated by a portion of the enclosing mineral.

Green spinel occurs in irregular, rather small grains, or granular aggregates.

A few fairly well-shaped crystals of zircon were noticed.

In a slice passing through the actual contact, there appears to be some injection of felspathic material. Prof. Barrois noticed that some of the inclusions were penetrated by very fine veins of the enclosing granite (especially rich in hornblende). In view of the considerable

amount of felspar found in the inclusions we may well suppose that some has been derived from the surrounding granite, for the metamorphism has evidently been very intense. Doubtless the inclusions were never in a state of igneous fusion; but there has been a sufficient amount of molecular freedom to admit of the formation of comparatively large, sharp-edged crystals of corundum, without many inclusions. The original sedimentary rock was probably poor in silica.

The presence of corundum in the enclosing granite has not been noticed; it would be interesting to examine the decayed rock, especially in the neighbourhood of the inclusions, in order to see whether any corrosion thereof has led to the presence of corundum in the granite.[1]

It is interesting to compare this occurrence of corundum as an undoubted contact-mineral in included fragments, with those described in Southern India by Mr. C. S. Middlemiss,[2] which are supposed to result from the metamorphism of foreign inclusions.

In conclusion, I have great pleasure in expressing my indebtedness to Prof. Barrois, who not only very kindly directed me to the Pont Paul locality, but also gave me full permission to describe the rocks. I have also to thank Prof. Bonney for allowing me to examine his slides of other altered rocks from Morlaix.

Discussion.

Mr. R. D. Oldham remarked that, in Southern India, more than one of the known occurrences of corundum had been recognized as being in the marginal portion of an intrusive mass. In one instance a direct causal connection appeared to have been established by Mr. T. H. Holland. The corundum of Sivamalai occurred in a coarse-grained felspar-rock intrusive in an elæolite-syenite, by whose fusion an excess of alumina seems to have been introduced into the intrusive rock. On the subsequent solidification of the last-named the excess of alumina crystallized out as corundum.

Mr. Parkinson called attention to a specimen on the table from one of the ellipsoidal masses found in the Charnockite Series of the Salem District (Madras Presidency). The mode of occurrence of these lenticles and the large amount of corundum that they contain make it extremely probable, according to the published accounts of the district, that they are altered inclusions of some foreign rock. He thought the specimen of interest in connection with the Author's paper.

[1] Compare K. Busz, 'On the Occurrence of Corundum produced by Contact-Metamorphism on Dartmoor' Geol. Mag. 1896, p. 492.

[2] 'Preliminary Notes on some Corundum Localities in the Salem & Coimbatore Districts' Rec. Geol. Surv. India, vol. xxix (1896) pp. 40–46; see also T. H. Holland, 'Corundum' pt. i of 'Economic Geology' in the reissue of the 'Manual of the Geology of India' Calcutta, 1898, pp. 18 & 39–43, and Mem. Geol. Surv. India, vol. xxviii (1900) 'The Charnockite Series' pp. 183 & 234.

12. *On the* Origin *of the* Dunmail Raise (Lake District). By Richard Dixon Oldham, Esq., F.G.S. (Read February 6th, 1901.)

Every visitor to the English Lakes, who has travelled by coach from Windermere to Keswick, must know the Dunmail Raise, that deep-cut wind-gap through the mountains which forms, if properly understood, one of the most remarkable natural features that it has been my lot to see, one of the most difficult of satisfactory explanation, and one which has not by any means attracted the attention that it deserves.

Cut down to a height of 782 feet above sea-level, the gap lies between the masses of Helvellyn (3118 feet) on the one hand, and High Raise (1500 feet) and the Sca Fell Pikes (3210 feet) on the other; it forms a typical instance of the lückenpass of Richthofen,[1] or wind-gap of the Americans, but differs from the majority of such in one important point which will be brought out in the sequel.

Approaching the pass from the north, there is seen a deep-cut valley, broad and open at the bottom, from which the sides rise steeply in, what Mr. Marr has named, the curve of erosion; it is, in fact, a typical stream-valley, and a valley properly belonging to a volume of water to which the term river is applicable; yet when this gradual ascent is traversed the road, after a short steep rise over a moraine, crosses an insignificant little streamlet, the Birkside Gill, which is utterly out of proportion to the valley down which it now flows, and is a very glaring instance of what Prof. W. M. Davis has called a misfit. As the road goes on, it traverses the same valley-shaped gap, which ordinarily contains no stream at all, till, at the summit, the Raise Beck is seen coming down from the east. Here is a case of divided drainage, for while the bulk of the water flows away to the south, a small portion, when the beck is in flood, finds its way to the valley which has just been traversed.

So far nothing extraordinary has been seen, the features are such as may be observed in any wind-gap due to the beheading of the stream which once filled it, but as soon as the descent is commenced a great contrast is noticed. Instead of a steep descent on the further side of the crest, the slope of the valley is at first almost imperceptible. Then come some large moraines, signs of erosion are seen in the stream-bed, there is a steep bit of descent in the road, but the valley maintains the same type as on the other side of the divide, and the Raise Beck is as glaring a case of misfit to the valley that it occupies as the Birkside Gill.

The commonest mode of origin of a wind-gap is when a stream

[1] 'Führer für Forschungsreisende' 1886, p. 703.

draining a considerable area, and consequently of considerable volume, has cut a deep valley and is then beheaded by another stream which, favoured by a steeper gradient, or cutting back along a band of soft rock, penetrates the drainage-area of the first and directs its headwaters to a new course. In this case, after a gradual ascent along an open valley, there is an abrupt descent from the summit-level to a deep-cut valley. Such is not the case in the Dunmail Raise.

Another form of wind-gap will not show an abrupt descent into a larger valley at the head of the gap, but will descend from the summit-level through (what Prof. W. M. Davis has called) an obsequent valley to a main valley crossing the head of the gap: an obsequent valley being one which has been cut back along the beheaded valley, on account of the lesser resistance offered by it, as compared with the higher ground on either side. In this case there will be an open valley on the one side of the summit-level occupied by no stream at all, or by a stream which is too small for it; on the other side the obsequent valley, having been formed by the stream which occupies it, will fit the stream that it carries and will be narrower and steeper-sided than the beheaded valley beyond the summit-level. This again is not the case with the Dunmail Raise.

A third mode in which a gap may be formed by erosion is where two streams opposite each other cut back into the same mass of high ground. Here the two valleys cutting back against each other will cause a notch to be cut in the ridge where they meet, but in such a case the summit of this notch will be narrow, if not sharp, and the slopes on either side steep. In an old land-surface which has long been exposed to denudation, and where all the surface-forms are rounded off by weathering, a notch with a cross-section not unlike the Dunmail Raise might originate in this way; but then the profile of the watershed would have a very different form, and in a hilly country of steep slopes and craggy summits the notch would have a shape much more like Striding Edge than the Dunmail Raise. Moreover, the streams draining from both sides of the watershed would fit their valleys, which is not the case in the Dunmail Raise.

In short, wherever a wind-gap is formed by the recession of watersheds, consequent on stream-action, the streams on one or both sides of the watershed must fit their valleys; and it is impossible in this way to form a gap in which the valleys on both sides of the summit-level are too large for the streams which now flow in them.

Another mode of origin which might be, though I am not aware that it has been, suggested, is that the gap was carved out by an ice-sheet. Against this hypothesis may be placed, first of all, the absence of any evidence of an ice-sheet having ever swept across these mountains; and secondly, a glacial origin seems precluded by the fact that at both ends the gap is crossed by the lateral

moraines of the glaciers which issued from the Wythburn Valley on the one hand and the Greenburn Valley on the other, while the central portion is dotted with heaps of avalanche-moraine,—that is to say, débris which rolled down the snow-slopes and was left on the ground when the snow melted away. The Birkside Gill shows old stream-gravels, washed down from the hills above, overlain by this avalanche-moraine material, indicating that the gap was in existence before the Glacial Period. The sides of the gap, too, where rock is exposed, show no signs of the ice-scouring which should have been most conspicuous if the gap had been cut out by ice; this is especially well seen at the southern end of the gap, where the spur between the Greenburn Valley and that of the Dunmail Raise has been smoothed and rounded up to a certain point by the glacier which overflowed from the former, and the boundary between the glaciated and unglaciated hillsides can be traced running down in a slant to the great moraines which lie at the southern entrance of the gap.

All this shows that the formation of the gap of the Dunmail Raise cannot have been due to ice, for the reason that it was in existence, in very much its present form, before the Ice Age commenced.

There remains, so far as I can see, but one other possible explanation, namely, that the gap was formed by a river which once flowed across the whole breadth of the Cumberland hills, whose volume and power were sufficient to enable it for a long time to cut down its channel as the hills were elevated, till, finally, whether from an increase in the rate of elevation, or a decrease in the volume and power of the river, or both combined, it was no longer able to do so, the river-valley was split into two portions, and the direction of flow of the upper waters reversed. In this way, and this way only, does it seem possible to explain the peculiar features of the gap which forms the Dunmail Raise.

This being so, it is of interest to determine whether the river flowed from north to south, or in the reverse direction, and here there is little room for doubt. In the first place we have the unequal slopes on either side of the summit-level: when a river-valley is crossed by a symmetrical axis of elevation, which splits it into two portions by the formation of a barrier across it and the reversal of flow of the upper waters, the slope will be steeper on what was the down-stream side than on what was originally the up-stream side of the crest; for, in the first case, the slope due to deformation is increased, and in the second diminished, by the original slope of the valley. Now, I find that the Ordnance Survey gives the height above sea-level at the summit of the pass as 782 feet; at Wythburn, 9 furlongs to the north, measured in a straight line, the level is 568 feet, giving a mean slope of 189 feet per mile; 7½ furlongs to the south of the summit the height of the road is 550 feet, or a mean slope of 247 feet per mile. If, instead of the heights on the road, those of the valley-bottoms are taken,

these slopes would be slightly increased, and in a larger degree on the south than on the north, so that the evidence of the surface-slopes points to the river having flowed from north to south.

A similar indication is given by the surface-features. As one travels southward from the Dunmail Raise the road descends into the broad and open valley of Grasmere; below Grasmere the valley contracts somewhat, but is still that of a larger stream than the one which formed the Dunmail Raise, and, a little farther on, the open valley of the Windermere Lake is entered. Travelling in the reverse way, we descend from the pass into the Thirlmere Valley, much narrower and steeper-sided than the valley on the other side of the pass, and at the lower end of the lake this valley divides into that of the Noddle Beck, through which the coach-road to Keswick runs, and the St. John's Vale, through which the waters of Thirlmere find their present outlet. Both of these valleys are smaller than the Thirlmere Valley, and St. John's Vale in particular has much more the aspect of belonging to the headwaters of a stream large enough to have carved out the gap of the Dunmail Raise, than of the lower part of its valley. It looks as if the two valleys represent two tributaries, which united at what is now the lower end of Thirlmere, to form a river, flowing southward to what are now Grasmere and Windermere.

It is noteworthy that the valley of the Noddle Beck is faced by the depression between Saddleback and Skiddaw, now drained by the Glenderaterra and Caldew, which may not improbably mark the course of the upper waters of the Dunmail River. It will probably be impossible to establish this definitely, and it must remain a suggestion; but it is not improbable that the diversion of the upper waters of the Dunmail River into the Derwent, and their removal to the west, may have caused such a decrease of power as to make the old river no longer capable of coping with the barrier, which was rising across its course lower down, and so caused the division of its drainage-basin and the ultimate reversal of the direction of flow of its upper portion.

Against the original southerly flow of this river can only be set the valley of the Wythburn, which joins the Thirlmere Valley, leaving an acute angle between it and the Dunmail Valley. An examination of the map shows, however, that the upper waters of this stream flow in a valley running at right angles to the course of the old Dunmail River, while the lower portion alone bends slightly northward, and the level at which this bend takes place is below that of the crest of the Dunmail Raise. It is, consequently, possible that the northerly bend of the lower portion of the Wythburn Valley is of a later date than the separation of the old Dunmail Valley into two portions, and due to the altered conditions of erosion set up by that separation. In any case, the obliquity of this valley would not preclude the possibility of a southerly flow of the river to which it was tributary, and against it must be set the bifurcation of the valley at what is now the lower end of Thirlmere, and the fact that on the south side of the watershed all the larger tributaries join the

main valley in what would be the normal direction for a southward-flowing river.

There remains the consideration of how the explanation of the origin of the Dunmail Raise offered above affects, or is affected by, the accepted ideas regarding the elevation of the mountain-mass which it traverses. Since the time of Hopkins's paper,[1] it has been recognized that the elevation to which these mountains owe their present existence is of much later date than the principal disturbance of the rocks composing them. In the paper just quoted, the axis of elevation is regarded as a linear one, the elevation attaining its maximum to the westward, in the neighbourhood of the Sca Fell Pikes, and lessening to the eastward. In more recent years the concept of a radially arranged drainage, originally due to the poet Wordsworth, has been taken into scientific literature; and in a geographical paper published by Dr. H. R. Mill in 1895,[2] the symmetry of the mountains is regarded as radial, not linear. He considers the mountains as carved out of a dome, traversed from north to south by two long depressions:—that of Thirlmere, Dunmail Raise, and Windermere, and that of Borrowdale, Stake Pass, and Conistone; and he illustrates his paper by a skeleton-map of the district, on which a series of circles are drawn round a centre on High Raise, midway between the Dunmail Raise and Stake Pass. On this map the lakes and principal valleys are shown to converge towards this assumed centre of elevation. In 1889[3] Mr. J. E. Marr had propounded the same view, and published a skeleton-map, very similar to that of Dr. Mill but without the concentric circles, and with geological indications showing that the present centre of maximum elevation is widely different from the axis of disturbance of the Palæozoic rocks. He considers that the only agency which could produce a dome-shaped uplift of the form postulated was the intrusion of a laccolite.

In the maps referred to, only the present lakes and river-courses are shown, and in them an appearance of radial symmetry can be easily detected, which disappears if the old Dunmail River is restored,[4] and also if a relief map of the district is examined. On a map of this character, it is seen that the mountain-mass is

[1] Quart. Journ. Geol. Soc. vol. iv (1848) p. 70.

[2] Geogr. Journ. vol. vi (1895) p. 46.

[3] Geol. Mag. 1889, pp. 150-55; see also Geogr. Journ. vol. vii (1896) p. 602.

[4] It is doubtful whether the Dunmail Raise is the only trace left of an older, now vanished, drainage. The Kirkstone Pass has much the appearance of a valley beheaded by the Stock Gill cutting back from the south, but the resemblance is not complete. The ascent of the valley, which drains northward, is not continuous to the summit, towards which it flattens off, and there is a slight descent, before the rapid drop into the valley of the Stock Gill is reached. This may be entirely due to the accumulations of morainic material on the summit; but it seems probable that the Kirkstone Pass had once the same form, and was originally due to the same cause, as the Dunmail Raise, and that the cutting back of the Stock Gill has been the cause not of the gap itself, but only of a modification in its form. If this be so, the Kirkstone Pass marks the valley of an old river, which formerly flowed from the north through Ullswater to the

divided into three portions, that of Skiddaw on the north—which lies outside the present discussion—of the Helvellyn-Shap Fell ridge, and of the Sca Fell-High Raise ridge; the latter being partially interrupted by the Stake Pass, as is the Helvellyn-Shap Fell ridge by the Kirkstone Pass. In each of these two masses, considered separately, the drainage can be better regarded as diverging from an axis than from a point. In the western mass, the drainage is more radial: we have it in Borrowdale flowing northward; in Buttermere flowing north-westward; Ennerdale towards the west; Wastwater to the south-west; while a ridge runs southward to the Old Man of Coniston, and breaks the drainage into smaller valleys flowing south-westward and south-eastward. On the opposite side of the Dunmail Raise the drainage is palpably axial: there are the two large valleys of Ullswater and Haweswater flowing north-north-eastward, and a number of smaller valleys drain the southern slopes of this ridge.

These two masses of high ground are separated by the gap of the Dunmail Raise; but this gap is in no way, or at most to a very slight degree, due to lessened elevation, the whole, or nearly the whole, of the depression being due to an excess of erosion. We may consequently leave it out of consideration in determining the original form of the elevated mass, or more properly that which it would have assumed had there been no denudation. Considered in this way, we find that it is not a dome, but a barrel-vault, terminating in the west in a semidome; to the east the axis continues beyond the area of the Lake District, and its further continuation need not be considered.

The recognition of an axis, as opposed to a centre, of elevation, does away with the necessity of attributing the elevation to the intrusion of a laccolite, but does not preclude the possibility of this cause, for there is no necessity for the symmetry of a laccolite to be radial and give rise to a dome-shaped elevation, though such is doubtless the most common form. A weightier objection is to be found in the history of the Dunmail Valley; the elevation of the hills evidently took place slowly, for a period sufficient to allow the river to lower its bed at least 2000 feet before elevation was able to master erosion. So slow and prolonged an elevation appears to be incompatible with its being caused by the intrusion of a laccolite, a cause which is likely to produce a comparatively rapid elevation of the surface.

Another point in which the explanation of the Dunmail Raise here offered comes into contact with previously proposed explanations of the origin of the surface-features of the Lake District, is

---

Windermere Valley, a river which was interrupted and divided at an earlier period than that of the Dunmail Raise.

The Stake Pass may similarly mark the course of a river which crossed this area from the north, flowing along what is now the Borrowdale valley; but of this I cannot speak, as I have not seen the pass.

that which concerns the origin of the drainage-system. This is generally regarded as having been marked out, in its main features, at the time of the original uplift on the surface of the Carboniferous, and possibly newer, rocks which are believed to have extended across the region now occupied by the mountains of the Lake District. In other words, the principal valleys are regarded as originally consequent on this uplift, their direction being determined by the slope given to the original plain, whether of deposition or marine denudation, and as being superimposed on the rocks out of which they are now carved. This last hypothesis is unaffected by the explanation of the Dunmail Raise here offered, but the first is seriously affected. If my explanation is correct, it follows that a well-established river crossed the uplift at the time of its commencement, and this river was sufficiently powerful to cut down its channel as the uplift proceeded, continuing for a long time as an antecedent river. This practically necessitates the conclusion that the surface, affected and modified by this elevation, was not a plain of marine deposition or denudation, but a peneplain of subaerial denudation,[1] and it is possible that the principal northern drainage-lines other than the Thirlmere Valley were determined by reversals of the original drainage of the peneplain, due to the changes of level and slope caused by the elevation, in which case the valleys are reversed; but it is more probable that the present drainage-system was largely determined by a modification of the old one through cutting back by erosion into the rising mass of high ground,[2] in which case the principal lines of drainage must be regarded as subsequent.

This is, however, subsidiary to the main object of this communication, the explanation of the Dunmail Raise. The questions of what was the original extent of the drainage-area of the Dunmail River, and of what was the origin of the other drainage-lines in the Lake District, demand a more detailed and extended study than I have been, or am likely to be, able to devote to them. They will in any case be difficult to answer, and in view of the great changes in the details of surface-forms wrought during the Ice Age, it may be doubted whether they will ever be capable of certain solution.

Discussion.

Dr. H. R. Mill said that he believed the radiate symmetry of the valleys of the Lake District was first referred to by the poet Wordsworth, who considered only the western half of the district with Sca Fell as a centre. He himself had used the idea of radiate symmetry as a convenient way of fixing the somewhat difficult configuration of the district in the mind of a reader unacquainted with the region; and while naturally interested and pleased when

[1] This conclusion will of course be strengthened, if the suggestion regarding the origin of the Kirkstone Pass (footnote [4], p. 193) is accepted.

[2] With the possible exceptions of the Borrowdale and Ullswater valleys, see footnote, p. 194.

Mr. Marr brought forward geological evidence of a dome-like structure having actually existed, he did not himself presume to express an opinion on the matter. He thought that the Author's theory might explain several features in the configuration, such as the inward trend of the Glenderamackin Valley, and the double basins which appear more or less distinctly in Derwentwater and Bassenthwaite Lake, which did not fit into the theory of dome-structure.

Mr. A. E. Salter asked whether the solid strata below confirmed the Author's theory of upheaval, and whether any fluviatile deposits of the old river postulated in the paper had been found. He was glad to note that the Author, with his wide experience, favoured the work of subaerial agencies rather than marine in explaining the phenomena observed.

Mr. J. E. Clark asked whether the Author had sufficiently considered the tremendous rainfall of the Lake District. The streams when quiescent give no idea of the tremendous volume hurrying down the valleys in storms: it has been said that the Derwent at Cockermouth carries more water to the sea than any other river in England. The Author's references to the morainic deposits near Dunmail Raise were hardly conclusive proofs that they were records of the intensest epoch of the Glacial Period. That was a time when almost all the area was ice-submerged, implying far more powerful effects.

Mr. A. Strahan reminded the Author that 'through valleys,' such as he had described, occurred in many mountain-regions. One traversing North Wales had been recently described by Mr. Lake, by whom a somewhat similar theory had been put forward. The Isle of Man was almost cut in two by such a valley, and others occurred in Scotland and elsewhere. The contoured map exhibited scarcely seemed to support the Author's contention that the region had been traversed from north to south by a main river. It showed that the water-parting of the Lake District, though of no great length, ran generally east and west, and that the high land composing it exhibited no such bisection as would have been produced by the passage of a main river. It presented various stages in the process of breaking down, and the case described by the Author was merely the furthest advanced of several examples. At that point the Wyth Burn, flowing northward, was overlapped by the headwater of the Raise Beck flowing southward. Between them the two streams left a narrow tract, in which a gap appeared to have originated by the crumbling away of the rocks along a line of weakness, possibly due to the outcrop of a soft bed or to a fault. The solid geology, however, seemed to have been left out of account. While not accepting the Author's conclusions, he thought the paper highly suggestive.

Mr. W. Whitaker, the Rev. J. F. Blake, and Mr. G. W. Lamplugh also spoke.

The Author, in reply, said that the photographs exhibited by him were taken by Messrs. Walmsley Brothers and Mr. H. Bell of

Ambleside. He had experienced personally the possibilities of rainfall in the Lake District, and had made allowance for it in his statement that the existing streams on the Dunmail Raise were misfits. An observer of any experience should have no difficulty in making allowance for variations in volume of streams, as the flood-marks were certain signs of the maximum volume attained by the stream. With regard to the solid geology he had said nothing, as that had been fully treated by other authors. He had contemplated the possibility of the depression of the Dunmail Raise being due to a band of softer rock, but could find no support for the supposition, either in the solid geology or in the form of the Dunmail Raise itself. The form of a valley depended on the rock in which it was carved; but this did not affect the progressive widening of the presumed Dunmail Valley from north to south, or the direction of the tributary valleys. In speaking of the extraordinary character of the gap, he had looked to the rarity of recorded cases of reversal of drainage by upheaval, to the recognition of the old valley across the barrier, and to the depth to which the old river had cut its valley through the rising mountain-mass before its course was finally interrupted.

13. Notes *on the* Geology *of* South-Central Ceylon. By John Parkinson, Esq., F.G.S. (Read January 9th, 1901.)

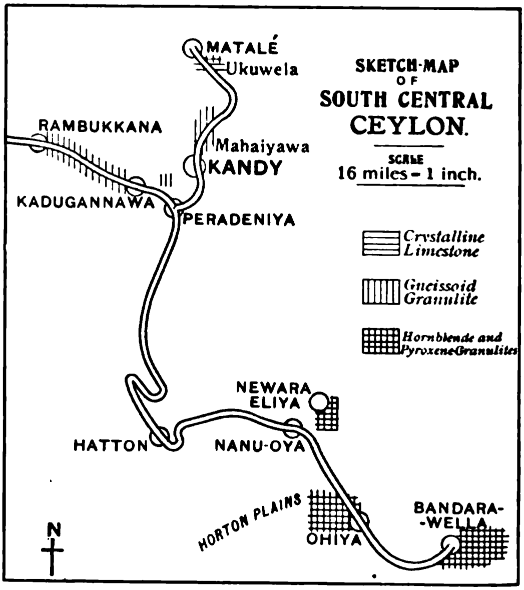
I. Introduction.

The following notes are the result of a tour of a few weeks' duration in the south-central parts of Ceylon. The time spent in the island was brief, and the work was done entirely upon inland sections; but in many places the exposures of rock are good, especially along the lines of railway. Petrological descriptions of Ceylon rocks are not wanting, but details of their field-relations are few, and it is hoped that the following paper may direct attention to the interesting problems which are likely to arise from such an investigation.

II. The Gneissoid Granulites.

(*a*) On the Ceylon Government Railway: from Rambukkana eastward in the direction of Alagala.—Leaving the station at Rambukkana, and proceeding along the metals, we walk over country which is flat, or nearly so, for about ½ mile, when we come to a small cutting. Here is exposed a rather coarse [1] granitic rock with pinkish-brown felspars up to ·3 inch across. In about 6 yards this gives place to one more finely grained, rather saccharoidal in appearance, and speckled with patches of mica.

Fig. 1.



On the opposite side of the railway-line the rock is banded, but not in the clear even way which, for instance, characterizes the gneiss on the south side of the St. Gotthard Pass. The darker parts are rich in hornblende and brown mica, and

[1] Granite and granitic are used merely as field terms; as will be seen, the structure of the rocks here described is not that of a granite.

contain little or no quartz. These bands often have a wavy habit, as though torn, and sometimes small black patches, like fragments of bands, appear isolated in the more granitic rock (see fig. 2). Rather frequently we find large felspars rounded in outline, and an inch or more in diameter. In 25 to 30 yards a very hornblendic rock crops out, followed in turn by one conspicuously banded. We find next the hornblendic rock veined by the granitic: some of the veins are only ·5 inch across, and frequently contain a fair proportion of the darker minerals. The hornblendic rock itself often exhibits much felspar. Sometimes long lenticular bands of the dark rock appear; at others it is represented merely by a few broken minerals.

Fig. 2.—*Banding in gneissoid granulite.* *(Total length figured = 10 inches.)*

A very fine section is exposed near the 54 bench-mark. This shows in some places the rock beautifully and wavily banded, the darker parts varying somewhat in their proportions of hornblende and mica, and hence in colour. In places a light-coloured vein cuts across an older banding, and yet seems to form an integral part of the rock; at others, the bands are disjointed and lie in fragments in the lighter matrix as though broken, while occasionally we find strongly-marked puckers. The granitic rock varies in texture, and sometimes, for a foot or so, is almost free from dark folia.

Thin sections show the dark rock to consist of a mosaic of green hornblende-crystals, extremely irregular in shape, and plagioclase, the former predominating in quantity. Occasionally, rounded grains of the hornblende are enclosed in the felspar. Apatite is very plentiful, and small zircons are not uncommon. The section also contains a little pleochroic augite with the characteristic colours of hypersthene. The specific gravity of the rock is 2·95.

The granitic rock, taken at a point where it possesses a minimum of hornblende or mica, is of medium grain and rather pink in colour. A thin section discloses microcline in considerable quantity, some orthoclase with micropertbitic intergrowth, and a good deal of plagioclase. Quartz is plentiful. In addition, the rock contains a few irregular flakes of biotite, zircon, and iron-oxide.

Specimens from the banded part of the same mass are characterized by rather small hornblendes and micas, often with a few larger

individuals of the former scattered through the rock. The specific gravity of such a rock is 2·82.

One possessing well-marked bands has a peculiar, though quite distinct foliation, making an angle of about 45° to the direction of the bands. Under the microscope the rock is seen to consist of plagioclase, orthoclase, quartz, green hornblende, a little brown mica, zircon, and apatite: the darker minerals predominating in certain parts, and, together with less quartz than in the remainder of the slide, constituting the banding. The proportion of mica varies, and in several instances it is associated with hornblende in a way which suggests very strongly its formation from that mineral. Iron-ores are abundant; for the most part they are probably ilmenite, together with some pyrites. The rock shows no indication of crushing, and the foliation referred to above seems probably due to a fresh movement preceding final consolidation, causing the mica-flakes to take up a new position oblique to the plane of banding.

(*b*) On the Ceylon Government Railway: westward from Kadugannawa.—Along the railway-line good but monotonous sections are exposed, essentially resembling those just described. The rock is both finely and coarsely banded, in some places the granitic veins measure 4 inches across, and although they frequently remain straight for some distance, yet they often vary in thickness, thinning out, then swelling. Occasionally the rock is gnarled, but this is not characteristic; while not infrequently the veins, by intersecting, produce an appearance of brecciation. This seems incompatible with any theory which would impute the banded structure to crush. A little farther west the rock, banded in its lower part, has a much more brecciated look in its upper. The whiter veins seem partly to enclose lenticular masses of the darker rock, and, in a few cases, to form a rather high angle with the underlying bands. In one case a long band of the darker rock, containing one or two small white bands, has been broken in two (fig. 3), so that probably the granitic rock is not all quite of the same age (fig. 4). Some coarse felspar-veins are certainly younger than the granitic rock which constitutes the more regular bands.

The cross-cutting granite-vein of fig. 4 is fine-grained and white in the hand-specimen, thereby differing from the granite described on p. 199. A thin slice exhibits large and very irregular grains of quartz, orthoclase in considerable quantity, microcline rare or absent, plagioclase, and a few greenish flakes of mica. The rock has a granulitic structure, the quartz usually penetrating the felspar, or in some places forming quartz vermiculé. Its specific gravity is 2·62.

A dark band (of specific gravity 3·28) in the banded rock below Kadugannawa shows in a thin section much pale-green augite, altering to darker green hornblende. A brown mica is present, often presenting the appearance of a further product of alteration,

but at others seemingly independent and in well-formed flakes with a distinct orientation. The rest of the slide consists of pyrites with some magnetite, untwinned felspar (not very plentiful), perhaps a little dolomite, and apatite.

Fig. 3.—*Banding in gneissoid granulite.*
(Total length figured = 4½ feet.)

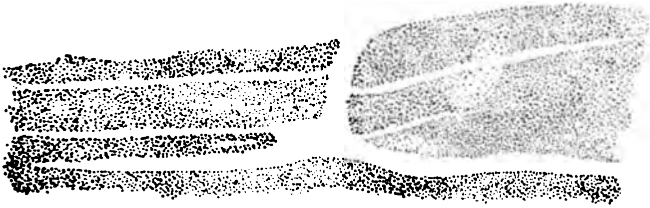


Fig. 4.—*Banding in gneissoid granulite.*

A thin section, from a well-banded specimen from the same cutting, exhibits both in constituent minerals and in structure a great resemblance to those already described in § (*a*). In the

lighter bands the only ferromagnesian mineral is a mica; the remainder consists of grains of quartz, plagioclase, and some orthoclase. The extinction of the plagioclase symmetrically with regard to the trace of the composition-plane varies from 7° to 9°. The darker parts of the slide are distinguished by large plates of green hornblende and a quantity of brown mica. The two minerals are intimately connected the one with the other; in one instance the mica seems to be an alteration-product of the hornblende. The constituent grains of the light and dark parts interlock, and there is nothing approaching to a sharply-defined line of contact. Quartz is less plentiful in the darker parts; a few grains of an apatite-like mineral occur, and an occasional crystal of zircon. There is very little quartz vermiculé, but no microperthite.

In the cutting just below Kadugannawa (that is, on the west) the banded rock becomes strikingly garnetiferous. The garnets favour the dark parts in their distribution, but occur also in the lighter. One or two are of the size of a very small pea, but this is exceptional. A typical specimen is dark and micaceous, markedly foliated, slabby in fracture, and crowded with small garnets, about ·025 inch in diameter. A thin section shows that hornblende is entirely absent, its place being taken by the garnets. These are irregular in shape, rather cracked, and may be either pyrope or almandine.[1] Occasionally we find mica-flakes embedded in the garnet. The plagioclase gives symmetrical extinctions from 18°—18° to 22°—22°.

A thin section has been cut from a specimen taken near the small wayside station of Balana, on the Colombo side of Kadugannawa. Here the darker rock is in excess, but the white bands are still clearly seen in places. Under the microscope we see it to be closely related to the series already described. It contains a considerable quantity of hornblende and mica in approximately equal proportions.

A thin section has been cut from a very similar rock cropping out on the path to Lanka Telika, near Kandy. It is a black and white speckled rock, the white constituents being granular and saccharoidal. Under the microscope the resemblance to the Balana rock is very great: the ferromagnesian silicates are somewhat less strongly developed, but iron-ores are not uncommon.

(*c*) Railway to the north of Mahaiyawa (Kandy).—A well-preserved banded rock is found to the north of Mahaiyawa. It sometimes contains quartz-grains of considerable size and, locally, garnet. Not far from this is a small quarry near the railway, excavated in a grey biotite-gneiss, streaked rather regularly by a red coarse granite, which occasionally contains large black mica-plates. The rock is often very coarse, and exhibits big eye-shaped felspars such as were seen near Rambukkana. The bands which this granite

[1] M. Lacroix refers the garnet to almandine, Bull. Soc. Min. France, vol. xii (1889) pp. 288, 306, etc.

forms run parallel with the general foliation, and from the field-evidence seem clearly to be an integral part of it. A slide cut from a fairly coarse specimen of the granite shows that it is essentially the same rock as that which forms the lighter-coloured parts in the cuttings near Rambukkana (p. 199). Both rocks are characterized by microcline and microperthite, and by the presence of large, very irregular quartz-grains, while the ferromagnesian silicates are represented in both by a few flakes of mica. A thin section taken from a specimen showing the banding of this rock with the biotite-gneiss demonstrates that no line of demarcation can be drawn between the two varieties, that is, that the whole must have solidified at the same time. The darker part, that called biotite-gneiss, consists of an interlocking mosaic of quartz and felspar, with orthoclase and plagioclase. A little microcline is found, and one or two grains of orthoclase contain microperthite. Biotite with a slight foliation is the sole ferro-magnesian silicate, and possesses the same characters as before. The specimen is almost identical with one from near Rambukkana.

A little farther north we come to a very slabby, rather fine-grained, and uniform pinkish 'granite,' the planes of parting being determined by mica-flakes. This 'granite' forms the greater part of the cutting, but the gneiss also appears, and specimens were taken showing the junction of the two. A thin section proves a perfect gradation between the two rocks, and both are characterized by the same type of structure.

The pink rock contains no ferromagnesian silicate at all (except the black mica just referred to), and is distinguished by a quantity of orthoclase with microperthitic intergrowth, though the mineral does occur without it, and a little plagioclase. The rest of this rock consists of quartz in small and very irregular grains, which frequently occur as inclusions in the felspar and *vice versa*. The other part of the slide (that is, the gneiss) contains orthoclase without a microperthitic intergrowth, large and very irregular quartzes, some plagioclase, and no microcline; in addition, we find a few flakes of mica. In passing from the pinker rock to that just described the first sign of change is the appearance of the larger grains of quartz, and then the gradual disappearance of the microperthitic structure. It seems clear that the pinkish 'granite' is a fine-grained representative of the coarse rock which streaks the biotite-gneiss in the small quarry above described.

The rocks of Kadugannawa, Rambukkana, and Mahaiyawa are usually well foliated, and commonly banded. The dark bands are characterized by green hornblende in varying quantity, and the association with this of a brown mica. Garnets are found locally. Field-evidence shows that the inter-relationship of the light and dark bands may be best explained by the streaking together of the component parts of a magma which had undergone differentiation, and that occasionally this process was carried to a rather unusual extent.

III. Contact of Limestone and Pyroxene-Granulite.

Railway between Matalé and Ukuwela.—On leaving Matalé Station we see, first, a few outcrops of white crystalline limestone, followed and overlain by hard red soil. This exhibits a number of small ferruginous concretions, which are, however, merely the outcome of a weathered condition, for internally it is mottled red and yellow, and is apparently an argillaceous soil rich in iron.

In a short distance we come to a level crossing, and on the left-hand side of the track a small section is disclosed by the railway-cutting. The dominant rock is a crystalline limestone, but in this, and looking like an approximately horizontal dyke, is a fine-grained rock rather saccharoidal on a fractured surface, but with a greasy lustre. This very closely resembles the pyroxene-granulites exposed on the road to Hakgala from Newara Eliya (see p. 207). This rock, which I will call 'the Band,' in order not to prejudge the question of its intrusive nature, is about 4 inches thick at the only place where its upper and lower surfaces are seen. It can be traced for about 5 yards, the base not being seen; and in one place it forks, and partly includes a mass of limestone about a yard square.

After this exposure, we find a good cutting of well-crystallized limestone (specific gravity $=2{\cdot}86$), followed by another of red rock similar to that seen before, but less concretionary on the weathered surface. This is succeeded in turn by limestone, and again by the red soil, which must be a kind of laterite.

Thin sections from the 'Band' and limestone will now be described. In a slide cut from a specimen of the former (specific gravity $=2{\cdot}96$) the dominant mineral is a pleochroic augite. In an orthopinacoidal section the colour for vibrations normal to the prismatic cleavage is a pale pink with a slight tinge of crimson; at right angles a pale, rather bluish, green. The pleochroism thus closely resembles that of hypersthene. The polarization-tints are brilliant, rather recalling those of olivine. Occasionally this augite is of a medium shade of sage-green, non-pleochroic or but feebly so, and probably merely a variety. Mixed in with this augite are a few irregular grains of pale red garnet, which are absent in a second slide. The augite is altering to brown hornblende, the pleochroism of which ranges from a yellow to a red-brown. There are also a few grains of pyrites. Brown mica occurs in other specimens. These darker minerals constitute the greater part of the rock. The rest of the slide is made up of clear and colourless plagioclase, with well-marked twins and extinction-angles of 14° to 17° (agreeing with oligoclase) on either side of the trace of the plane of composition.

A thin section, cut from a specimen showing the contact between the 'Band' and the mass of limestone which appears to be included in it, exhibits points of interest. The aspect of the 'Band' is greatly altered. It is fine-grained, rather pink in colour, and discloses no distinctive minerals when examined by the naked eye. The limestone is not so coarse as in the cutting nearer Ukuwela,

but is crowded with green malacolites. At the junction exists a line of dark minerals. Under the microscope the 'Band' is represented by a fine-grained aggregate of calcite and malacolite, the latter preponderating, the former interstitial. The smaller grains of malacolite are full of inclusions, perhaps of a carbonate. The limestone consists of plates of dolomitic calcite,[1] and is exceptionally rich in malacolite, thus resembling the rock on the other side of the junction, except that the carbonates predominate over the malacolite, and the whole is coarser. The last-named mineral becomes more plentiful as we approach the boundary, and is also serpentinized along cracks and edges; while near the junction many grains are converted into yellow and green serpentine. The line of demarcation between the two rocks consists of greenish and yellow serpentine, without definite form and showing but few traces of its origin from malacolite.

A second contact-section, cut from another specimen a couple of yards or so away, unfortunately gives but little information about the composition of the 'Band' near the junction. We find the same serpentinized zone; and the line of demarcation between the two rocks is not strongly marked, so that it is difficult to say where one begins and the other ends. This section is, however, noteworthy for the grains of spinel embedded in the serpentine-zone. There is some iron-oxide, possibly of the nature of a residue, and a few small flakes of reddish-brown mica, almost colourless for vibrations normal to the basal plane. The spinel is of a dull sage-green, considerably cracked, and occurs in rounded subangular grains up to ·025 inch in diameter.

Perhaps some monticellite may be present, as well as malacolite. The limestone 12 inches from the junction contains abundant grains of malacolite, fresh and not serpentinized, and a few plates of slightly-coloured augite. The dolomitic calcite here and in the cuttings to the south often has a vermiculated structure, owing to the presence of threads of a colourless mineral with an exceedingly low index of refraction and apparently no action on polarized light.[2] Very rarely we find a few flakes of yellow-brown mica, and still less frequently a grain of spinel. Prisms of pale blue apatite are common, ranging up to ·07 inch in length. When detached entirely from the rock and examined in polarized light we find them to be strongly dichroic (pale blue to pale claret-red).[3]

A specimen of the 'Band' distinguished by the presence of large brown plates of mica, 1 to 1½ inches across, deserves a few words. The rock is much lighter in colour than normal specimens. A thin section shows that there are three primary minerals and one

[1] The rock effervesces sharply with cold hydrochloric acid. See Bull. Soc. Min. France, vol. xii (1889) p. 336, where the presence of both calcite and dolomite are recorded by M. Lacroix.

[2] An identical structure is described and figured by M. Lacroix in the dolomite of these rocks; see Bull. Soc. Min. France, vol. xii (1889) pp. 337–38 & fig. 60.

[3] See A. K. Coomára-Swámy, Quart. Journ. Geol. Soc. vol. lvi (1900) p. 600; Lacroix, Bull. Soc. Min. France, vol. xii (1889) p. 339; and C. Barrington Brown & J. W. Judd, Phil. Trans. Roy. Soc. vol. clxxxvii (1896) A, p. 212.

secondary—the former are malacolite, mica, and spinel, the last-named brownish hornblende. This replaces the malacolite completely in many places.[1] It is yellowish-brown for vibrations parallel to the prismatic cleavage, and possesses a fairly strong absorption. The mica includes plates of the hornblende, and extends its irregular edges amongst the hornblende-crystals. It is brownish-red for vibrations parallel to the basal plane, and pale straw at right angles to this direction. The mica also encloses small grains of green spinel, which make only the faintest attempt at an idiomorphic outline. The same mineral occurs embedded in the malacolite, and occasionally forms conspicuous aggregates which measure ·1 inch across. The malacolite-grains are closely packed together, cracked, and rather stained. Very commonly the hornblende and mica contain a large number of small rounded greenish inclusions, with a high refractive index. They are so minute that their double refraction cannot be safely estimated, but it seems that a regular gradation can be traced from them to indubitable grains of spinel, and it may be inferred that they are that mineral.

The laterite-exposures found alternating with those of the limestone must originally have been represented by a crystalline rock of some such type as that described from the west of Kandy or from the neighbourhood of Bandarawella.[2] Accordingly we find the less difficulty in correlating the small rock-mass termed the 'Band' with those between Newara Eliya and Hakgala, which it closely resembles. The presence of crystalline limestone above and below this 'Band' and the way in which it partially encloses a mass of the former are unaccountable by any explanation other than that of intrusion.[3]

IV. Hornblende and Pyroxene-Granulites.

(*a*) The neighbourhood of Bandarawella.—In the quarry on the hillside above the station we find a garnet-bearing hornblende-felspar-quartz rock with a very granulitic structure (specific gravity =2·76). It is often well banded, the more felspathic containing much quartz, but frequently such parts, instead of forming bands, occur as patches coarser than the rest. The felspar is greenish, which gives the rocks a rather dark appearance, and, by the aid of the quartz, a greasy lustre. Occasionally we find large eye-shaped felspars about 1·5 inch in length. A typical specimen is a finely-banded rock, the darker parts being composed of garnet, magnetite, and hornblende. These bands vary in breadth from about ·1 inch

[1] Some iron must be present in the original mineral.

[2] Decomposition *in situ* seems to be the true explanation of the formation of this type of soil in Ceylon.

[3] I am of opinion that the peculiar mineralogical composition of the two rocks described above, namely, the representative of the 'Band' at the junction with the limestone, and the malacolite-mica-spinel rock, may be best accounted for on the hypothesis that local incorporation of the limestone accompanied the intrusion.

to mere lines. To these three constituents the microscope adds a mineral, which I think is apatite. The magnetite is often embedded in the garnet; its outlines are irregular or sinuous. An angle or a side of the garnet is often finished off by hornblende, and flakes of the latter frequently connect small outlying grains of the former. A few crystals of zircon are present. Quartz is abundant, and occurs in the usual elongated grains, which occasionally divide and ramify among the other constituents. The felspar is, for the most part, orthoclase with microperthitic intergrowth; but a little plagioclase is found.

In some specimens the garnetiferous parts of the rock are represented by a short band, about ·4 inch broad, composed almost entirely of garnet, while in other places the mineral is aggregated into patches.

A specimen collected at the station before Bandarawella is essentially the same as the banded rock of the quarry above described. It is compact and greenish in colour, slightly banded, and with a greasy lustre. The irregular outlines of the garnet and their association with green hornblende, magnetite, and the apatite-like mineral, merely repeat the characters of the Bandarawella rock. A very few flakes of brown mica are found. The largest garnet is about 0·10 inch in diameter.

Similar rocks are met with by the new road which runs along the side of the hill above Bandarawella village. The numerous cuttings usually show the common sandy soil, which seems certainly to result from the disintegration *in situ* of the gneiss. The bands which characterized that rock are still clearly visible, and even the remains of the garnets can be seen as reddish spots. A few small quarries and road-cuttings show a little variation in the character of the rock. Sometimes no garnets at all appear, and the rock is uniform when seen from a distance. Frequently, however, closer inspection reveals the presence of a few dark bands (specific gravity =3·16). Such an one possessed green hornblende as its dominant constituent, while a pleochroic augite was common, and biotite not rare. The rest of the slide was composed of plagioclase, as usual quite translucent.

A thin section cut from a banded rock near here showed that, as in all instances met with of banded rock in Ceylon, no line of demarcation could be drawn between the dark and light portions of the slide. The darker parts contain hornblende and pleochroic augite; and, more sparingly, magnetite, brown mica, and garnet in order of frequency. The greater part of the hornblende is an alteration-product from the augite. The remainder of the specimen is a light greenish rock containing large quartz-crystals, but as a whole much finer in grain than those from the Station Quarry at Bandarawella. Some red garnets about ·03 inch in diameter catch the eye, and also a few flakes of mica.

(*b*) Road from Newara Eliya to Hakgala.—In the quarry at the end of the lake at Newara Eliya occurs a dark greenish

rock, with greasy lustre and some variation in degree of coarseness. Felspar is present in considerable quantity, and also conspicuous elongated grains of quartz.

A specimen, less finely grained than usual, has been sliced for examination. The ferromagnesian silicates (both biotite and hornblende) are inconspicuous. The two constituents which build up the greater part of the rock are quartz and orthoclase with microperthitic structure. Some of the felspars measure ·4 inch across. The quartz is occasionally micropegmatitic, and accessory minerals are plagioclase, zircon, pyrites, and (?) apatite.

Cropping out by the side of the road to Hakgala, close to the quarry just mentioned, is a garnet-bearing rock closely related to the above, but more finely-grained and richer in the ferromagnesian silicates (specific gravity $=3·11$). A little farther on, in a quarry on the left bank of the stream, the rock of the Newara Eliya quarry appears. The rock is traversed by coarser quartz-felspar veins, essentially the same as the coarse patches from the Newara Eliya quarry, and in these rather large flakes of mica are scattered. Occasionally the mica-flakes have a distinct orientation.

A small exposure above and to the right of the road consists of a banded garnetiferous gneiss, containing some quantity of pink felspar and a good deal of quartz. A vein or band of pink felspar and quartz, recalling the pinker parts of the gneiss (from which indeed it cannot be separated), traverses the rock roughly parallel to its foliation. It measures about 3 inches across, and contains patches of mica. No hard-and-fast line, as of a contact, can be drawn between the two.

About 230 paces down the road we find the compact greenish rock of the Newara Eliya quarry (specific gravity $=2·66$). Thin sections prove that this type is identical with the pinkish banded gneiss, in spite of the rather striking difference of colour: hence there can be, I think, no doubt that they form one group.

A well-banded rock crops out about ½ mile below the entrance to Hakgala Gardens. The more felspathic part is compact, greenish-yellow, of uniform texture, of specific gravity 2·59, and contains a pyroxene and a few inconspicuous red garnets. The pyroxene is monoclinic and pleochroic, but the pink colour which distinguishes this mineral elsewhere is almost imperceptible. The rest of the section consists of an aggregate of quartz, orthoclase (microperthite and microcline absent) and plagioclase (extinction 7°), and a few grains of zircon.

(c) Ohiya.—The rocks of the railway-cutting between Ohiya and the ascent to Horton Plains are identical with those of Newara Eliya and the road to Hakgala, so that a detailed description is unnecessary.

Taken as a group, these rocks are distinguished, with a few exceptions, by a greenish colour accompanied by a greasy lustre, and usually by the presence of garnets. These garnets are associated with hornblende, a pleochroic pyroxene, magnetite, and

frequently biotite. Irregular grains of quartz are common. There can be, I think, no doubt that these rocks are closely related to those of § II, p. 202.

Mr. T. H. Holland,[1] in a most valuable memoir, describes 'a group of Archæan Hypersthenic Rocks in Peninsular India' under the name of the Charnockite Series, and states that members of it occur in Ceylon. Some stress is laid by Mr. Holland on the presence of the rhombic pyroxene. So far as my work goes, it tends to show that hypersthene is not distinctive of the Ceylon rocks. I have not, in fact, found the indubitable mineral at all (though it has been recorded by Mr. A. K. Coomára-Swámy), but a monoclinic pyroxene with the pleochroism of hypersthene does occur.

The preceding observations show that the series of igneous rocks studied are closely related one to the other, and have arisen through the variation of a single magma. This variation, in places, has resulted in a well-marked differentiation into acid and basic parts which, by subsequent intermingling, have produced a banded gneiss. Further, the evidence brought forward indicates that these rocks are younger than the crystalline limestone and are intrusive into it.

In conclusion, I wish to express my indebtedness to Prof. Bonney, D.Sc., F.R.S., for valuable suggestions and help during the preparation of this paper.

Discussion.

Dr. J. W. Evans said he believed that the granulites described by the Author appeared, like those of Southern India, to fall into two classes: the hypersthene-granulites, grouped by Mr. T. H. Holland in the Charnockite Series, which were usually comparatively massive rocks; and highly-banded granulites, in which hypersthene was absent or played a subordinate part. The latter were well seen in the auriferous beds of the Kempinkote Mine, where they might be considered as quartz-diorites with a granulite-structure.

Gen. McMahon said that the President had alluded to the probability that the Ceylon rocks described in the paper under discussion are connected with the Charnockite Series of Peninsular India, and he understood that the Author considered the banding and foliation observable in the Ceylon rocks to be due to causes similar to those relied on by Mr. Holland: namely, the flow of the magma during the process of consolidation.

Mr. A. K. Coomára-Swámy said that he regarded the conspicuous mineral-banding seen in many Ceylon rocks as representing a sort of fluxional structure acquired at the time of consolidation. The rocks seemed to be practically unaffected by earth-movements of a shearing or crushing character, but exhibited structures which are probably original.

[1] Mem. Geol. Surv. India, vol. xxviii (1900) p. 119.

Mr. Barrow noted the resemblance of the specimens and slides to those from Deeside. There the gneisses are largely of sedimentary origin, and among them is a limestone closely resembling that described by the Author. Did he consider that his limestone was of sedimentary origin or not? If he did, how was the absence of all other sediments to be accounted for? Some of the specimens claimed as igneous contained structures which were characteristic of altered sediments, and had never been met with by the speaker in the igneous gneisses. One of the supposed igneous rocks (a fine biotite-garnet-gneiss) bore a close resemblance to an altered sediment which occurs close to the Galloway granite.

Prof. Bonney said that these rocks of Ceylon were especially interesting because they had, on the whole, escaped from the effects of crushing. He had not understood the Author to deny that the marble had once been a sediment, but he had his doubts as to the banded gneiss to which Mr. Barrow assigned that origin. It was also very interesting to get interchange of materials between the intruding and the older rocks. It would be worth while trying to ascertain under what circumstances this mixing occurred.

Mr. Prior pointed out that many of these rocks from Ceylon could be matched from the gneissic and granulitic rocks of tropical East Africa; but since this was equally true of rocks from Deeside, as stated by Mr. Barrow, he did not feel inclined to use it as an argument for the former connection of Africa and India.

The President and Mr. R. D. Oldham also spoke.

The Author, after thanking the Society for the very kind way in which they had received his paper, said, in reply to Dr. Evans, that he had subdivided the granulitic rocks described as far as he felt to be wise, but that the structural and mineralogical resemblances of the whole were so close that he felt compelled to regard them as products of one magma. He concurred with Gen. McMahon in the opinion that the foliation and bending of the Ceylon rocks were not due to earth-movement; in this his work agreed with that of Mr. Coomára-Swámy. In reply to Mr. Barrow he said that the limestones occurred to a very limited extent within the area described, and that the question of their origin was outside the scope of the paper. Concerning the igneous origin of the other rocks he felt not the slightest doubt, since appearances in the field and the evidence obtained by means of the microscope clearly indicated such a conclusion.

14. The Hollow Spherulites *of the* Yellowstone *and* Great Britain. By John Parkinson, Esq., F.G.S. (Read March 6th, 1901.)

[Plate VIII.]

Contents.

I. Introduction.

In a paper which I had the honour of presenting to the Geological Society some time ago on the Pyromerides of Boulay Bay,[1] I explained the formation of these nodules by supposing the extrusive magma in which they were produced to be imperfectly mixed and in a somewhat viscous state, a conclusion which facts in the field appear amply to justify. These, and other nodules which I studied in North Wales and near Wrockwardine, led me to suppose that the dominant characteristic of these peculiar structures was not that of spherulitic growth, which rather was secondary, and that the principal cause operating in their formation, as just remarked, was a clotting in the magma by a process of flow-brecciation. At the same time, I did not suggest that this was the sole means by which pyromerides were produced, and moreover I purposely left some of the structures which are found, notably the not infrequent concentric arcs of quartz, for later consideration and discussion. Recently, in crossing the American continent, I made a detour to the Yellowstone Park with the object of studying the obsidian there, and it is the result of this excursion which has led to the putting together of the following notes. Since the paper above referred to was written, I have examined the rocks of Boulay Bay and Wrockwardine for the third and second times respectively, and have studied those of Pontesford Hill.

The general features of the National Park of the United States are too well known to need more than brief mention; I would, however, refer to the recent monograph by Prof. Iddings in the Memoirs

[1] Quart. Journ. Geol. Soc. vol. liv (1898) p. 101.

of the United States Geological Survey, vol. xxxii, pt. ii, and to the Geologic Atlas of the United States, folio 30. The latter contains the Survey maps and a general description of the topographical and geological features, together with a brief summary of the igneous rocks by Prof. Iddings.

I have studied these acid lavas at two points: firstly, at the well-known Obsidian Cliff, and, secondly, at the Cañon of the Yellowstone River. The rocks at these two localities differ one from the other in a most unusual manner. At Obsidian Cliff is seen a magnificent section of an obsidian lava-flow, the lower two-thirds columnar, the upper part crowded with large hollow spherulites; at the Cañon the effect of solfataric action on the rhyolite has converted the great thickness of these flows, which now form the walls of the Cañon, into the friable many-coloured rocks which constitute one of the greatest attractions of the Park.

[Part I—The Yellowstone.]

II. Description of the Rocks of Obsidian Cliff.

The glass.—At Obsidian Cliff this is black, but in other places, as, for instance, locally at the Cañon, a streaking together of red-brown and black glass is not uncommon. Where spherulites abound, the glass of course decreases in quantity, merely filling interstices, and is occasionally almost entirely absent. In a thin section the glass appears clear and transparent, and crowded with trichites and microlites.[1] It is too well known from the work of Prof. Iddings to require any description.

The smaller spherulites admit of division into two groups:—

(i) This contains bluish-grey spherulites which are usually solid, hard, and compact in texture, with a well-marked radial structure. Not infrequently, the interior of the spherulite becomes hollow, and the cavities of adjacent individuals communicate. These hollows have a tendency to be stellate in outline, and not rarely the greatest length is normal to the direction of the flow-band. Their walls are usually formed of a narrow layer of brown earthy material, external to which we find the harder bluish-grey spherulite.

(ii) In this subdivision radial structure is almost entirely absent, and cavities are invariably found. A thin border of whitish, rather crumbly material around the cavity represents the spherulite, and strings of such forms are embedded in the black glass. Occasionally we find an approach to the harder blue spherulite of the foregoing group, the more coherent material being external to the white crumbly layer. Lines and bands of these spherulites are common in the lower parts of the obsidian-columns, and often measure only ·025 inch across. The cavities are large in proportion to the diameter of the spherulite, and are almost always arranged with their longer axes normal to the direction of flow. When the

[1] See Iddings, 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 273 & pl. xv.

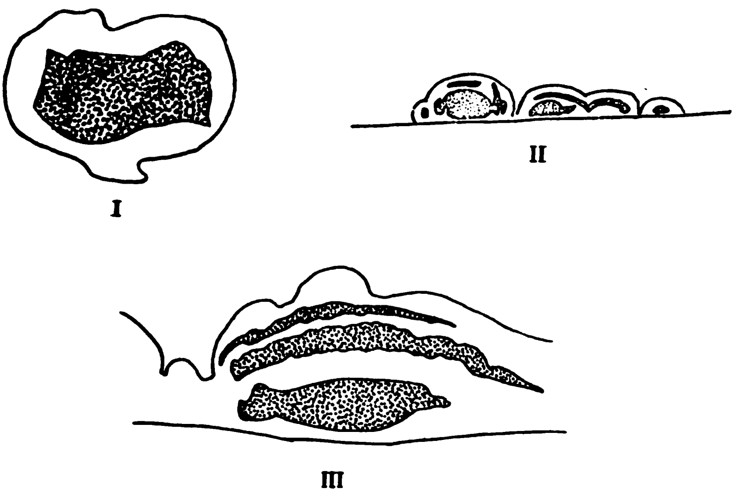
cavities of adjacent individuals communicate, these hollows naturally become irregular; and often the whitish material is aggregated in porous or cavernous bands or clots, measuring up to ·5 inch across.

Hollow spherulites proper.—If any large slab of rock forming part of the talus at Obsidian Cliff is examined, it is seen that the cavities of the spherulites possess many shapes. Often they exhibit a concentric disposition around a large central hollow; sometimes the concentric arrangement of smaller cavities is almost absent; in a third case the vesicles are irregular and even stellate; while in a fourth they are almond-shaped and elongated in the direction of flow.

These cavities will be considered under two heads:—

(i) Those without definite form.[1]—One example, irregularly stellate, was surrounded by a mere shell of spherulitic growth in which a radial structure was just discernible (fig. 1, I). The

Fig. 1.—*Cavities in the spherulites of Obsidian Cliff: natural size.*

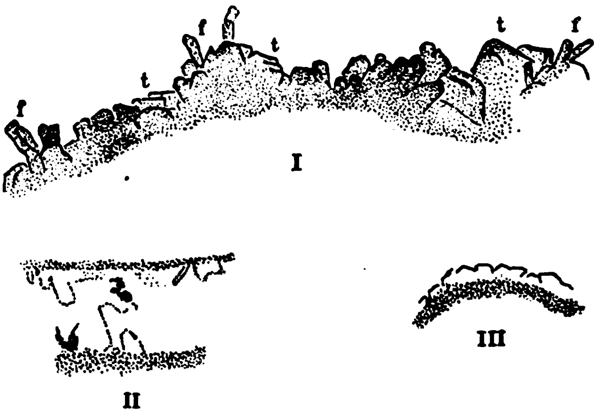


spherulite itself was pale pinkish-white in colour, and the interior of the cavity and part of the wall, as seen on a fractured surface, were granular. Crystals of fayalite were embedded in and on the walls. The exterior of the spherulite was slightly irregular, a small blunt tongue projecting out in one place into the surrounding material. This consisted partly of glass, partly of lithoidal flow-bands. The stellate form of the cavity may be best conveyed by imagining that a blunt wedge was thrust outwards from the cavity into the yielding substance of the spherulite. In one place the walls met at a right angle.

[1] See Iddings, 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 264, pl. xii. figs. 1 & 5.

(ii) Cavities with a definite form.—Almond-shaped cavities, frequently elongated till they resemble a rift in the rock rather than an ordinary vesicle, are common. Such a rock resembles a series of plates, 1 inch thick and upwards, imperfectly welded together, and containing many interspaces. Usually these plates are lithoidal, but contain patches and streaks of the black glass. For instance, we find an elongated porous spherulite an inch or so in length, contained between two hard compact flow-bands and embedded in glass at either end. It consists of an aggregate of crystals which in places are only loosely set together, and at one end contains three small hollows, the greater length of which is at right angles to the direction of flow. Such a spherulite, when the cavities are more fully developed, presents an arrangement of concentric rings lying in a plane parallel to the flow-bands. This is the typical lithophysal structure.[1] The concentric rings, which in a cross-section bridge a cavity, consist of a rather coarse granular aggregate of crystals of felspar and tridymite (fig. 2). From the

Fig. 2.—*Hollow spherulites.*



I = Outer edge of one of the series of concentric rings which distinguish the lithophysæ of Obsidian Cliff, showing the projecting crystals of tridymite (*t*) and felspar (*f*). ×40.
II = Interspace between two rings of a lithophysa from near Wrockwardine, showing remnants of projecting crystals (see Pl. VIII, fig. 2). ×45.
III = Remnants of a mineral resembling tridymite, from near Wrockwardine. See p. 221. ×45.

almond-shaped rifts we obtain gradations to other kinds of hollow spherulites. Thus, by decreasing the length of the cavity parallel to the plane of flow, and broadening it in a direction at right angles to that plane, we arrive at an ordinary hollow hemispherical spherulite lying on a flow-band. Such a cavity shows relation to

[1] See Iddings, 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 264 & pls. xii & xiii; for chemical analyses of the obsidian and lithophysæ, see *ibid.* p. 291.

its spherulite by a parallelism at the ends of the latter, or by its general concentric form. On the flat surface of a specimen we often see an arc-like disposition of cavities subtending angles up to 180°; two such arcs are often concentric one to the other.

One fine pink spherulite measuring about $1\frac{1}{2}$ inches by 1 inch, clearly traversed by the flow-lines which run through the rock, possesses an open and porous texture, preserving at the same time its spherulitic habit. On the upper side of a flow-band, and, as it were, springing from it, the spherulitic growth is distinctly visible to the naked eye, and by the aid of a low-power lens is resolved into bundles of branching rays, the free ends of which project into a crescent-shaped cavity. Much tridymite adheres to these fibres, but above the rift the spherulite is more solid in texture and the radial structure less readily recognizable. Through this part fine flow-lines can be traced. Below the band coarse tufts again appear, also connected with a cavity, and extend for the entire length of the spherulite. These fibres pass into the more compact portion of the spherulite, and apparently differ in no respect from it except in habit.

In this instance the cavities of the spherulite are related (*a*) to a flow-band, and (*b*) to the periphery of the spherulite.

The lithophysæ of Obsidian Cliff graduate into another common variety, distinguished by a porous structure and by the absence of a definite cavity. An entire absence of a cavity is, perhaps, rare, but it is not structurally important. Such forms may be conceived of as lithophysæ in which the cavities have been distributed through the body of the spherulite and not localized or arranged in a definite way. These porous spherulites are irregular, lobate, or circular in outline: often the outer zone is harder and less friable than the central portions, and shows traces of a radial growth.

III. Statement of the Problem.

The preceding description demonstrates that no distinction can be drawn between the various kinds of spherulites described. Even the bands of hard bluish-grey spherulites are found frequently to possess small central cavities, and by gradation to merge into those in which the cavity is the dominant feature. Between such and the typical lithophysæ no distinction can be made that would indicate a difference in mode of formation, since all stages can be observed connecting the two.

It remains, then, to see what explanation best accords with the varying forms of structure which the rock presents, and if possible to bring to light the fundamental property of the original magma to which they owe their birth; or, on the other hand, to see whether decomposition by heated waters may not be responsible for the whole or for part of the observed facts. To this end, let us investigate first the effect of solfataric action as revealed in the rocks of the Yellowstone Cañon.

IV. The Effect of Solfataric Action in the Cañon of the Yellowstone.

In a road-cutting within a few yards of the Upper Falls of the Yellowstone is a dark chocolate-coloured rhyolite, streaked with a brighter red, and containing many porphyritic crystals of felspar and quartz. The rock possesses a fluxional structure and numerous fragments attributable to flow-brecciation. In a thin section it appears brown and opaque, with a very obscure spherulitic structure, together with a rather blotched appearance as though the constituents had gathered themselves into a series of nodes and irregular patches. These are separated by light-coloured streaks consisting of tridymite and opacite. In a few yards the character of the rock changes considerably. Small spherulites weather out from the dark grey surface, but fracture discloses a reddish-purple rock studded with porphyritic felspars, and especially noteworthy for the milky-white cavernous patches spread through it. In a thin section we see that no dividing line can be drawn between altered and unaltered parts, so insidiously has the intruding silica permeated, and so gradually does the change take place. The staining of the rock, probably by iron, and the obvious silicification which it has undergone, are no doubt due to the permeation of hot water charged with silica, and apparently during this process parts of the rock have been entirely removed.

A specimen of uniform milky-white rock, containing light grey fragments in such quantity as to recall an ash, was collected from the crags overlooking the Great Falls of the Yellowstone. Within a couple of yards we find pale grey spherulites about an inch in diameter, which for the most part, at least, are not hollow. Probably, then, the rock is a rhyolite, and the fragments are due to flow-brecciation. A thin section shows that the structure of the rock has been preserved, save for a slight indistinctness in the outline of the fragments. More transparent patches, such as distinguished former specimens, are not found, and streaks of opaline silica are not uncommon. Between crossed nicols there is no action on polarized light.

A few slides of spherulites from a friable obsidian near the Upper Falls of the Yellowstone have been prepared, and are of some interest. Firstly, they are almost identical in form and structure with their far older representatives of Boulay Bay, except for the greater number of porphyritic crystals that they contain; and secondly, they bear no evidence of silicification or alteration.[1] In a thin section the type of radial growth strongly recalls that of Boulay Bay and of the small blue spherulites of Obsidian Cliff. The slice

[1] This statement admits of some modification. Occasionally one finds an oblong or irregular patch, more translucent than its surroundings, and distinguished by the absence, more or less complete, of the felspathic fibres, and by the presence of a colourless almost isotropic substance which may be tridymite.

is brown and rather opaque, exhibits the mottled appearance of the Northern Jersey rocks, and traces of flow-structure exist. Porphyritic crystals of quartz, unaltered orthoclase, and plagioclase are common, the last predominating. In one slide an elongated cavity is cut through, into which a porphyritic, absolutely unaltered orthoclase projects. This cavity is lined by rather impure carbonates, while some discoloration of iron-oxide exists in the neighbourhood, but no sign of replacement or of solution. This indicates that the spherulite is more resistant to the action of hot water charged with silica than are its surroundings.

The cavernous hollows with a rough mammillated lining, found in the altered rhyolites of the Upper Falls, and referred to above, closely resemble at first sight some spherulites with irregular vesicles from the obsidian of Obsidian Cliff. The concretionary material which lines the cavities in the rock of the last-named locality is easily powdered, and consists of branching rays of dusky felspar and tridymite. In the altered rhyolite the similar material is much harder, and no felspathic fibres appear. The encrusting substance is probably largely tridymite, which mineral it resembles in its index of refraction and polarization-tints; but the characteristic hexagonal outlines are not seen, perhaps owing to the fact that the constituent scales are more closely aggregated.

We may conclude that, the action of hot water charged with silica may be to remove portions of the rock, or to permeate it without destroying its characteristic structure; we obtain, however, no evidence, but rather the reverse, to show that the spherulites are most easily attacked.

V. Conclusions in regard to the Yellowstone.

The theory formulated by Prof. Iddings[1] to account for the structures exhibited by lithophysæ at Obsidian Cliff and elsewhere in the National Park is, in my opinion, that which is most in accord with the facts. It is based on the hypothesis that the origin of lithophysæ is due to the hydrous state of certain parts of the magma. In an additional memoir, recently published,[2] three physical processes have been given as the means by which the formation of lithophysæ was carried out. These are, in the first place, rapid crystallization; in the second, 'a sudden liberation of heat' resulting therefrom; and in the third place, a consequent 'lowering of saturation of the surrounding mother-liquor.' Thus he arrives at the 'spasmodic advance of crystallization' resulting in 'layers' of varying coherence, and the ultimate formation of open spaces by 'shrinkage.' In order to test the truth of these hypotheses by independent data, I have consulted Berthelot's 'Mécanique Chimique' and kindred works, and have also

1 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 284; for an historical review of the theories relating to lithophysæ, see *ibid.* p. 287.

2 Mem. U.S. Geol. Surv. Monogr. xxxii, pt. ii (1899) p. 417; see also Bull. Phil. Soc. Washington, vol. xi (1891–92) pp. 446–47.

endeavoured to obtain information concerning the latent heat of liquefied felspar, but without success.[1]

In a cooling magma we may conclude that the temperature gradually falls to the saturation-point when crystallization commences, and the rise in temperature produced, if any, would do little more than counteract the loss of heat due to the cooling of the magma as a whole.

If the part under consideration became supersaturated, some rise of temperature, no doubt, would ensue, though to what extent is doubtful. Supposing, however, heat to be produced by crystallization in a supersaturated solution, one deduction must be made for leakage into the surrounding rock, a second to counterbalance the fall of temperature in the whole mass, and it is only the balance which can be devoted to 'lowering the saturation of the surrounding mother-liquor.'

We find, then, some probability, at least, that the means which Prof. Iddings suggests are inadequate to the required end. In my opinion, that author's earlier work is more nearly in accord with the facts, and it is with this that the following remarks closely agree. No doubt can exist that when crystallization commences we have to deal with a hydrous patch in the magma, and that in this, as the temperature falls, anhydrous minerals develop. It is, therefore, clear that the remaining liquid—no doubt in a very viscous state—would become more hydrous, and the occluded vapour would be pushed away from the crystallizing zone, though part would be entangled in it and produce the characteristic porous structure. We have at this stage a comparatively solid portion succeeded by a vapour-laden belt, followed in turn by another area in which solidification is commencing.

The solid state of the part crystallized, and the viscous state of that in the act of crystallization, would prevent diffusion; and the process would be continued, until the whole of the hydrous patch presented the characteristic concentric structure.

[Part II—Great Britain.]

VI. Boulay Bay (Northern Jersey).

These peculiarities of structure in the spherulites and lithophysæ of the Yellowstone can often be paralleled in those at Boulay Bay and elsewhere in Great Britain, and thus afford great help in any investigation concerning the latter. Not infrequently in the old lavas we find concentric arcs composed of quartz, and roughly parallel with the periphery of the nodule. Occasionally the outermost is broad and well-defined, those nearer the centre progressively being less well marked (Pl. VIII, fig. 1). This tendency to fade away is shown (i) by the quartz-filled arcs becoming smaller; (ii) by the various portions of the arc becoming disjointed the one from the other, so as to produce a segmented appearance; and (iii) by the

[1] I wish to record my indebtedness, for invaluable help in this matter, to Prof. T. G. Bonney and Principal E. Carey Foster.

quartz-filled space itself becoming partly obliterated, owing to the presence of felspathic outgrowths principally from the convex side of the dividing walls. Passing towards the centre of the nodule we find, at last, the crescent-shaped areas represented by irregular grains of discoloured quartz, spread like cirrus-clouds through the brown nodule.

A perfect network of felspathic rods is seen also in many Boulay-Bay slides occupying the end of a crescent-shaped space, where this passes into the surrounding rock; while adjacent parts of the nodule appear to consist of felspathic fibres embedded in quartz. In the same way a haphazard section of a spherulite may show branching fibres of felspar projecting outward from a centre.

The felspathic outgrowths common enough in the nodular rocks of Boulay Bay are exceptionally well seen in the very similar rock from near Wrockwardine. In one instance the crescent-shaped rings are formed about a central amygdaloid. These rings, now consisting of infiltrated silica, are about ·035 inch across, and each is formed by two or more elliptical arcs joined together. From the convex side of these arcs spring rod-like growths of felspar, visible even to the naked eye, in a thin section. They stretch occasionally half-way across the quartz-filled space, and, in some instances at least, appear to have influenced the deposition of the infiltrated silica, for the mammillated layers can be seen to bend over the projecting fibres. (See fig. 2, II, p. 214, and fig. 3, p. 220.)

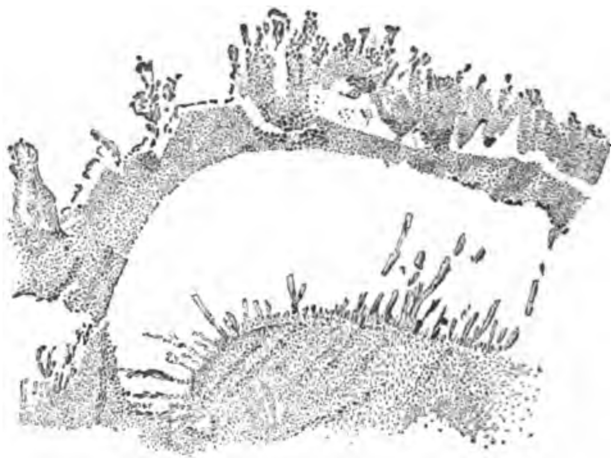
Not uncommonly at Boulay Bay we find evidence to show that porphyritic crystals of fairly large size, comparable with the fayalite of the Yellowstone lithophysæ, were present in this much older rock. They occur in a rather puzzling series of specimens from Boulay Bay and the Tête des Hougues, which possess a marked flow-structure, and appear to have been very vesicular.

A thin section of one rock shows that the greater part is spherulitic, and possesses a mottled appearance due to the separation of the particles during crystallization into a rather opaque greenish-yellow substance and a more translucent yellowish-brown one: both being fibrous. Many spherulites in the immediate neighbourhood exhibit precisely the same structure. In this rock lie innumerable amygdaloids, usually oval, and in some slides joined together so as to produce a rather vermicular appearance. The original vesicles, now filled wholly or partly with quartz, are sometimes lined by an irregular spherulitic growth stained with iron, containing specks of opacite, and slightly coarser than the opaque material surrounding it. Frequently we cannot define accurately the internal limit of this spherulitic ring, since the earliest layer of infiltrated quartz is usually discoloured. As in the hollow spherulites from Obsidian Cliff, the interior of the vesicle must have been exceedingly rough and uneven, and was probably provided with projecting spurs penetrating the cavity. A thin section, passing near the edge of such a spherulite after it had been filled up, would present a very confused arrangement between the infiltrated and the original materials. Occasionally a distinct lithophysal structure is found on a small scale.

In one or two instances a thin arc of quartz separates the inner spherulitic zone from the mottled fibrous material surrounding it; in others, curved or branching lines traverse the latter, and define a series of spaces, each possessing a distinct fibrous growth which differs in direction from that of adjoining areas. Such quartz-filled arcs and lines may be best accounted for by the supposition of contraction round a vesicle as described by Prof. Bonney.[1]

In another example the greenish material, but faintly mottled and with practically no radial structure, appears to have resolved itself into a number of globular forms roughly connected one with

Fig. 3.—*Parts of two rings of a lithophysa from the Wrockwardine district, showing the fibrous felspathic outgrowths.* $\times 30$.



[Undotted spaces are filled with quartz.]

the other. A very confused crystallization, resembling that seen before, occupies the interspaces: these, for the most part, consist of discoloured quartz, separated indistinctly from the greenish matrix, which often seems produced outward into them in a hazy indefinite way. Embedded in the interspaces are the remnants of lath-shaped crystals, now entirely replaced by secondary products, and scarcely to be distinguished between crossed nicols from their surroundings. These, I think, are felspars; and I am led to this identification by comparison with other slides where an indubitable felspar has been altered in exactly this way.[2]

In other sections we find long lath-shaped crystals projecting into, or apparently lying altogether in, a cavity. They consist of a skeleton of iron-oxide, recalling the common alteration-product of

[1] Quart. Journ. Geol. Soc. vol. xxxviii (1882) p. 289.

[2] See 7th Ann. Rep. U.S. Geol. Surv. (1885–86) p. 267, for the description of felspars in the lithophysæ and the cavities connected with them in the Yellowstone region.

mica. These crystals seem to be strictly analogous to those found projecting into cavities at Obsidian Cliff.

Evidence with the microscope and in the field shows that here is a series of rocks which were originally very vesicular lavas. A narrow margin of spherulitic growth formed around the vesicles, which appear either isolated or arranged by flow in a vermiform way through the rock. Points of resemblance can be found in those small blue spherulites of Obsidian Cliff which contain a central cavity. It was mentioned in Pt. I (p. 212) that these have a layer of brownish and somewhat friable material interposed between the central hollow and the compact hard outer zone; and probably it will not be erroneous to conclude that the distinct zone surrounding the vesicles of the Boulay-Bay rock is due to the presence of heated vapour from which the adjacent rock-material was unable to free itself during solidification.

VII. Wrockwardine (Shropshire).

The rhyolites of the district near Wrockwardine are well known. The greater part of the rock is of a dark chocolate-brown colour, as are also the nodules and smaller spherulites. Frequently surrounding the latter, and intermingled with the brown rock, is found a dark-green, rather soft substance, which is apparently of the nature of a residual glass. The nodules are usually lobate in outline, and stand out from a weathered surface much less commonly than is the case at Boulay Bay and in North Wales, and more frequently exhibit lithophysal structure.

Fig. 4.—*Cavities of lithophysæ from near Wrockwardine, now filled by infiltrated silica: slightly larger than natural size.*

This consists of a system of rings analogous to those from the Yellowstone region, which closely follows the periphery of the enclosing nodule, and may or may not surround a central quartzose amygdaloid (Pl. VIII, fig. 2 and text-fig. 4). The very complicated form which the entire system frequently assumes is due, I believe, to pressure after solidification: this pressure has broken down the concentric rings of rock, and usually connected the cavities to the central hollow when such exists.

The practical identity in the structure of the lithophysæ from the Yellowstone and Wrockwardine is still further emphasized by the presence, in the latter, of the remnants of a mineral which closely resembles tridymite in external form. It is rather sporadic in its occurrence, but locally encrusts thickly the walls of the concentric cavities of the spherulite. It is now replaced by quartz, so that the original polarization cannot be determined.[1] The outward form of the original mineral can still be observed, owing to the presence of some impurity in the infiltrating material which has preserved its outline by a thin encrustation. Sections in one plane are lath-shaped, measuring about ·003 inch × ·0006 inch, and in a plane at right angles to the former the shape is that of a hexagon. The complete hexagon has not been observed, two sides being absent where the mineral joins the wall of the amygdaloid; this is most usually the case in the tridymite of the Yellowstone. Often only two sides of the hexagon are seen. The general habit of the mineral strongly recalls the encrusting tridymite of the Yellowstone lithophysæ, and there can be no doubt, at least, that it is not due to deposition, in some unusual manner, by the infiltrating silica.

One rather interesting point follows. In some of the rocks a thin section reveals the presence of a number of incomplete spherulites, often fragmentary in appearance, and surrounded by secondary quartz. The structure is due partly to the presence of original gas-vesicles, partly perhaps to movement subsequent to the formation of the spherulites, and partly to brecciation after solidification.

Sometimes, however, the outlines suggest some amount of corrosion. It is possible to fix a date for the latter, owing to the typical development of the mineral resembling tridymite on such a corroded surface. We may suppose that the circulation of heated waters through the rock effected some corrosion, though not, I think, to any great extent, and that subsequently, when the temperature fell somewhat, tridymite, or a mineral closely resembling it, was deposited. (See fig. 2, III, p. 214.)

The obsidian of the Yellowstone region contains so large a number of porous spherulites, that in any investigation of older lavas at all comparable with the American rock one must be prepared to find indications, and probably abundant indications, of these peculiar structures.

The felspathic fibres, described and figured in the foregoing pages as projecting into the cavities of the spherulites from the old flows at Boulay Bay and Shropshire, as well as the open, non-compact nature of those parts of the spherulite which are adjacent to such cavities, show how closely these older lavas approximated to the younger in the conditions under which they solidified. The formation of a mineral suspiciously like tridymite clearly points in the same direction.

[1] The replacement of tridymite by quartz has been described by M. E. Mallard, Bull. Soc. Min. France, vol. xiii (1890) p. 161, from the Euganean Hills.

VIII. Pontesford Hill (Shropshire).

The rock of the north-western corner of this hill is almost identical with the rhyolite of Boulay Bay, and the nodules are quite indistinguishable from those of that rock.[1] The quartz-amygdaloids are rather irregular in shape, not infrequently stellate, and occasionally show some relation to the periphery of the enclosing nodule. As at Boulay Bay, lithophysæ are not common, and occasionally radial structure is not appreciable to a lens. The material in which the nodules are embedded is frequently greenish-brown, presumably once a glass, and contains small spherulites: it bears a very close resemblance to the devitrified glass of Boulay Bay. In thin sections we see that the nodules possess a well-marked spherulitic structure, resembling that observed in the Boulay-Bay rocks, but, in the cases examined, rather coarser than is usual in the Jersey examples. Admirable examples of the tufted form of growth are common, and these frequently project from part of the nodule into the quartz-amygdaloid. The resemblance to the structures already described from Boulay Bay and Wrockwardine is so close that no further mention is necessary.

IX. North Wales.

I have examined the nodular rock at Beddgelert (in passing), at Conway Mountain, and in the region of the Conway Falls and the Lledr Valley. In a former communication[2] I have referred to these rocks, and have nothing to add to what was then said. In the majority of cases, I believe that the conclusion brought forward by Prof. Bonney holds good:—namely, contraction around a cavity.[3]

X. The Hypothesis of Corrosion.

The continuity of lines of flow on either side of the star-like elongations of a central cavity have been considered[4] as a clear indication of corrosive action, and as a strong argument against the former presence of a vesicle which would have diverted the lines of flow. But we may also suppose that these star-like spaces arose from contraction on cooling, and consequent cracking which caused rupture without disturbing a structure previously acquired. In the hollow spherulites of Obsidian Cliff, irregular vesicles, with an inclination to be angular and even star-shaped, are far from uncommon, and apparently quite analogous to those from the older rocks.

Another feature brought forward in favour of the hypothesis of

[1] I am indebted to the kindness of Mr. W. Boulton, Assoc.R.C.S., who is engaged in a study of the rocks of this district, for permission to insert these remarks on Pontesford Hill.

[2] Quart. Journ. Geol. Soc. vol. liv (1898) p. 112.

[3] *Ibid.* vol. xxxviii (1882) p. 289.

[4] G. A. J. Cole, Quart. Journ. Geol. Soc. vol. xlii (1886) p. 183 & pl. ix, fig 1; see also Miss C. A. Raisin, *ibid.* vol. xlv (1889) p. 261.

corrosion is that brecciation-cracks widen in passing from matrix to spherulite.[1]

The nodules of Boulay Bay are frequently traversed by large numbers of brecciation-veins of different ages,[2] formed as a rule in radial directions, since these are the planes of easiest parting. In some the edges are distinct and sharp, in others they are blurred. On the whole, they are more numerous in the nodules than in the matrix. The older brecciation-veins are frequently clouded with brownish material, and disappear almost completely from view between crossed nicols, owing to the resemblance of the infilling material to that which constitutes the walls. As described in a former communication, a characteristic of these nodules is to break up, between crossed nicols, into a mosaic of interlocking irregular grains: often these are in optical continuity with the vein-substance. Indeed, in the older cracks we can nearly always find evidence to show that the sides are closely knit together, while in the newer the edges are sharp cut.[3]

The polygonal contraction-cracks around sundry spherulites from Boulay Bay do not appear abnormally wide, and they have of course been exposed to the action of any hot springs or fumaroles that may have existed. There seems, then, to be evidence, not of a widening by corrosion, but of a healing of the old fracture, and it is difficult to see how corrosion could act when once the vein was filled by so refractory a cement as silica. Were it half filled, and the means of transport less effectually blocked, the case might be different.

XI. General Conclusions.

In the second part of this paper I have endeavoured to elucidate some of the structures of the old lavas of Great Britain by a comparison with those of the Yellowstone region.

We have found in the rocks of Boulay Bay and Wrockwardine that the nodules contain amygdaloids of crescentic shape, passing into more or less completely circular rings, and we have compared these directly with the lithophysæ of the American obsidian. Moreover, we have found that felspathic fibres project outwards into a quartz-amygdaloid, that parts of some nodules show an open network of similar fibres now embedded in secondary material, and we have been able to draw a direct analogy with the porous spherulites of the Yellowstone. Finally, traces have been found of an encrusting mineral curiously resembling tridymite. All this militates strongly against an hypothesis of corrosion, so that we need feel no hesitation in applying to the older spherulites of Great Britain a conclusion which appears in accord with the facts observed in the rocks of the National Park of the United States.

In the case of the large amygdaloids, irregular, partly circular

[1] Quart. Journ. Geol. Soc. vol. xlii (1886) p. 185 & pl. ix, fig. 2.
[2] *Ibid.* vol. liv (1898) p. 115 & pl. vii, fig. 1.
[3] The brecciation-veins traversing the nodules of Pontesford Hill present identical features.

FIG. 1.

FIG. 2.

LITHOPHYSAE FROM BOULAY BAY AND WROCKWARDINE.

or stellate in outline, I conclude that at these spots were gas-vesicles: such gases having been disengaged from the surrounding rock at the time when solidification began. In the case of the crescentic or annular amygdaloids I conclude that at these spots the magma was in an extremely hydrous state, and that the area now enclosed by the periphery of the nodule was practically composed of two parts, that is, magma and water. Hence the excess of either would crystallize out or separate out, as the case may be. As in the Yellowstone, the water charged with sundry substances in solution probably played some part in depositing encrusting minerals on the surfaces of the cavities.

In conclusion, I wish to express my grateful thanks to Prof. Bonney for much kind help in the microscopical work, and also for suggestions concerning the arrangement of the various parts of the paper.

EXPLANATION OF PLATE VIII.

Fig. 1. Lithophysal structure in a nodule from Boulay Bay. × 4.

2. Lithophysa from near Wrockwardine. The left-hand side is slightly dusty. On the right-hand side, the glass in which the lithophysa lies is visible. × 4.

Discussion.

Prof. Bonney congratulated the Author on the good use that he had made of his visit to the Yellowstone region, and expressed concurrence with the results at which he had arrived. The paper would put an end to the idea (in which the speaker had never believed) that hollow spherulites were formed by decomposition at the centre, and it had shown them to have been formed about an original cavity. Discontinuity of any kind, as the speaker had pointed out in 1885, was peculiarly favourable to the formation of spherulites. In the case of glass-bottles, softened by heat, they developed abundantly from the inner and outer surfaces; and similarly in sheets of glass, which had become adherent through heat. In the case of the formation of a spherulite round a cavity, crystallization might be facilitated by the pressure of the imprisoned vapour being outwards on the enclosing hardening mass; but in other cases, before that had time to produce an effect, the vapour, contracting more rapidly than the rock, might cause strains in it: sometimes, as the Author had suggested, magma and vapour might be mixed in the interior, producing either alternating zones of rock and excluded vapour, or loose spongy crystallization. As the audience had not properly seen the slices, owing to the partial failure of the lantern, he might say that he had examined the supposed tridymite in the British specimens, as well as the other structures described by the Author, and thought the former presence of that mineral highly probable, for that it should be replaced by a quartz-paramorph was not unlikely. He thought that the Author had proved that what the Yellowstone obsidians now were, this the felstones of Boulay Bay, Pontesford, and Wrockwardine had once been.

The Author briefly replied.

15. *On a* Remarkable Volcanic Vent *of* Tertiary Age *in the* Island *of* Arran, *enclosing* Mesozoic Fossiliferous Rocks.—Part I: *The* Geological Structure, by Benjamin Neeve Peach, Esq., F.R.S., L. & E., F.G.S., and William Gunn, Esq., F.G.S.; Part II: Palæontological Notes, by Edwin Tulley Newton, Esq., F.R.S., F.G.S. (Read March 20th, 1901.)

[Communicated by permission of the Director-General of H.M. Geological Survey.]

Part I. The Geological Structure.

During the progress of the geological survey of the Island of Arran Mr. Gunn mapped the network of igneous rocks that occurs about halfway between Brodick Bay on the east and Machrie Bay on the west, and lying to the south of the String Road which crosses the island from Brodick to Shiskine and Blackwaterfoot (Sheet 21 of the 1-inch Geological Survey Map). These rocks form the mass of high ground culminating in Ard Bheinn (1676 feet), A'Chruach (1679 feet), and Beinn Bhreac (1649 feet), whence the headwaters of the Glen Cloy Burn and Benlister Burn drain to the east and the Black Water and Machrie Water to the west. The area in which these igneous rocks are exposed has obviously been a focus of great volcanic activity. It may be compared with some of the larger and more complex vents of Palæozoic and Tertiary age in Scotland, but it is exceptionally gigantic in its proportions. It is oval in shape, and covers an area of about 7 to 8 square miles. Its greater axis, which trends east-north-east and west-south-west, is 3½ miles long, and its shorter axis is about 3 miles in length. It is surrounded by various formations, ranging in age from the Lower Old Red Sandstone to the Trias. On the north side, conglomerates, sandstones, and mudstones of Lower Old Red Sandstone age, dipping steeply south-eastward, strike obliquely against its northern margin. On the east side, the Lower and Upper Old Red Sandstone, followed conformably by the various members of the Carboniferous system, are truncated and altered by the igneous rocks. On the east side also, these are followed by Triassic sandstones, resting unconformably upon Carboniferous rocks, and, like them also, truncated and altered. Along the southern margin, the intrusive rocks of the area abut upon strata of the Lower Old Red Sandstone, which here dip southward and eastward, and are profoundly modified in places near the contact. On the west side, the Lower and Upper Old-Red-Sandstone rocks and the Triassic sandstones and marls are truncated and altered by the igneous rocks. The result of the detailed mapping clearly shows that the igneous rocks, which are crowded together within the area here described, must be later in date than the present disposition of the surrounding sedimentary formations, and

even of the important faults affecting them—a conclusion which is fully borne out by the alteration produced upon all these environing rocks at their junction with the eruptive masses.

The igneous rocks are made up partly of fragmental volcanic materials and partly of various intrusive masses. The area in which the fragmental rocks occur, measuring $2\frac{1}{2}$ by $2\frac{1}{4}$ miles, is confined within an almost unbroken ring of intrusive igneous rocks chiefly of acid character, and is invaded by numerous sheets, bosses, and dykes of varied composition, some of which are in visible connection with the rocks of the margin. Two smaller areas of fragmental material also occur, one surrounded by the marginal igneous rocks, the other enclosed between them and the outside sedimentary strata.

The pyroclastic material varies greatly in texture and composition. In places it is comparatively fine-grained, and made up of a paste of felspathic débris, in which occur lapilli, bombs, and large masses of various igneous rocks ranging from basic to highly acid composition, and both of volcanic and plutonic character, the acid varieties being by far the most abundant. In addition to these igneous fragments, fine débris and masses of sedimentary rocks like those of the environment appear in the agglomerate. In places, these increase to such an extent that the felspathic paste due to igneous débris disappears, and rocks are produced which might at first be mistaken for portions of the surrounding formations. Especially is this the case where the conglomerates of the Lower Old Red Sandstone have contributed large numbers of pebbles of quartzite and andesite, though a closer inspection shows that a great number of the derived pebbles are broken. Large masses like the sedimentary rocks, and evidently derived from them, are also found embedded in the agglomerate, and partly or wholly enveloped in the intrusive igneous rocks.

But the most remarkable of these inclusions consist of masses of shale, marl, limestone, and sandstone which belong to formations not now found *in situ* in the island. One of these, several acres in extent, occurs near the edge of the area $\frac{1}{4}$ mile north-east of Dereneneach, and is well exposed in a section cut by the Allt nan Dris, a tributary of the Machrie Water. It consists of dark shales and limestones, associated with and apparently underlain by grey marls, which in turn appear to be underlain by red marls resembling those forming the highest visible zones of the Trias in the island. From the dark shales and thin limestones of this mass Mr. Macconochie, in May 1900, obtained a suite of Rhætic fossils, in which he found a form referred by him to *Avicula contorta*. The mass, which is thus proved to be of Triassic age, is bounded on the east and north by agglomerate, and on the west and south by felsite and granophyre, which there form the margin of the volcanic area.

Another large fossiliferous mass of shale associated with impure limestone, partly embedded in agglomerate and partly in intrusive igneous rock, occurs near the head of Ballymichael Glen, $\frac{1}{2}$ mile due south from the top of Ard Bheinn. In this mass Mr. Peach

and Mr. Gunn found a small suite of fossils, which from examination in the field seemed to them to indicate the Liassic age of the patch—a correlation subsequently confirmed by Mr. Newton.

About 200 yards farther down Ballymichael Glen from the above locality Mr. Peach and Mr. Gunn noted blocks of limestone with nodules of flint or chert, in which they detected foraminifera and other organisms. The character of the rock, together with the organisms, suggested the probability of the masses having been derived from Cretaceous rocks in the condition of those now found in Antrim. A large mass of similar limestone and chert, associated with sandstone and shale, forms a cave (Pigeon Cave) situated 1100 yards north-east of Dereneneach, where it is underlain by agglomerate and overlain by a basic igneous rock. Although the limestone and chert are much altered, organisms were detected in them by Mr. Peach and Mr. Gunn, and subsequently by Sir Archibald Geikie, who, when inspecting the ground with Mr. Gunn, made a collection from this spot.

Another example of a limestone-mass, associated with sandstone and shale, caught up in igneous rock occurs on the hillside, 550 yards south of the farm-house of Glenloig, where it was formerly quarried for lime. The rock is free from chert, but too much metamorphosed to preserve recognizable organisms.

Other patches of sandstone and shale, believed to be of Mesozoic age, occur either embedded in the agglomerate or caught up in intrusive rock, but as yet they have yielded no fossils.

So far as has been observed during the detailed mapping of the ground, the intrusive igneous rocks are later in date than the agglomerate. While in composition they range from basic to highly acid material, in structure they pass from felsitic to granitic rocks, and there is further a distinct petrological sequence in the intrusions, the more acid rocks cutting the more basic.

From the foregoing summary of the evidence relating to the volcanic vent of Ard Bheinn the following conclusions may be drawn:—

(1) The great development of conglomerate, sandstones, shales, and marls covering the southern part of Arran may now be regarded as undoubtedly of Triassic age.

(2) The fossiliferous patches of Rhætic and Lower Liassic strata found in the agglomerate indicate the former extension of these formations in the South-west of Scotland, while the sequence of (*a*) red marls at the base, (*b*) grey marls in the middle, (*c*) dark shale and limestone at the top, recalls the development of these formations in the North of Ireland and in South Wales.

(3) The fossiliferous patches of Upper Cretaceous limestone and chert show that strata of that age once extended into the basin of the Clyde, and no doubt covered the surface of the area on which this Arran volcanic focus appeared. The huge

masses of Mesozoic shale and of hard Chalk now found in the vent must have fallen down from above into the vent, as has happened in the Palæozoic strata in some of the Carboniferous vents in Scotland.

(4) The igneous rocks of the vent are thus of post-Cretaceous age, and may be confidently assigned to the great Tertiary Volcanic Series of this country.

(5) From the absence of recognizable blocks in the agglomerate belonging to the formations intervening between the Lower Lias and the Chalk, it may be inferred that these intervening formations were never deposited in this region, or had been removed by denudation before Cretaceous time, as in the North of Ireland.

(6) The geological features of this volcanic area furnish impressive testimony as to the vast amount of denudation that has taken place in the South of Scotland since the period of Tertiary volcanic activity.[1]

Part II. Palæontological Notes.

[Plate IX.]

The peculiar circumstances under which were found the fossils that form the subject of these notes have been dealt with by my colleagues, and it will be sufficient to state here that the masses of rock from which they were obtained do not appear to be *in situ*, but are believed to be fragments of strata once existing in the district but now entirely removed by denudation.

1. Rhætic Series.

The first collection of fossils supposed to be of Rhætic age and obtained by Mr. Macconochie from Shiskine in May 1900, was forwarded to me for examination. The fossils themselves were in a dark, almost black shaly limestone, were very obscure, and their age was uncertain, for they proved to be too fragmentary to allow of definite specific determination, and it seemed possible that they might after all be of Carboniferous age. The search was continued by Mr. Macconochie, and a further collection was obtained and forwarded to me. The occurrence of undoubted specimens of *Avicula contorta*, together with other forms, proved beyond doubt the Rhætic age of the beds. A brief account of this discovery was published in the Director-General's Summary of Progress of the Geological Survey for 1899, p. 133.

[1] The fossils described by Mr. E. T. Newton in Part II were mainly collected by Mr. Macconochie.

Fossils of Rhætic age from near Shiskine (Arran).

* Found in the North-east of Ireland in the *Avicula contorta*-zone.

*Avicula contorta, Portlock. Several specimens clearly referable to this species.

*Pecten valoniensis, Defrance. Two or three fairly good specimens agree with the shells that have been thus named.

*Schizodus (Axinus) cloacinus, Quenstedt. One or two examples of shells with a sharp posterior keel are believed to be referable to this species.

*Protocardium philippianum (?) Dunker (= *C. rhæticum*, Merian). Two or three specimens probably belong here, but are not sufficiently perfect to make their identity certain.

*Modiola minima (?) Sowerby (= *minuta*, Goldfuss). A specimen about 20 mm. long and others larger are doubtfully referred to this species.

Estheria minuta (?) Goldfuss. An imperfectly-preserved impression may perhaps belong to this form.

*Gyrolepis Alberti (?) Agassiz. A broken fish-scale showing a few ridges may be provisionally referred to this species.

2. Lower Lias.

At a later date, and from another locality near Shiskine (see p. 228), my colleagues, Mr. Peach and Mr. Gunn, procured from a mass of strata a collection of fossils, which in due course was forwarded to me. These were in an entirely different matrix, and so fragmentary that their determination was difficult, although it seemed highly probable that they were of Liassic age, one fragment being apparently referable to *Ammonites angulatus* and another to *Gryphæa arcuata*.

A second and larger series, collected by Mr. A. Macconochie from the same locality, fully confirm the earlier provisional determinations and afford positive evidence of the presence of Lower Lias in Arran. The rock containing these fossils is much decomposed, and for the most part in a very friable condition. The fossils themselves have entirely disappeared, and are now represented by internal and external casts. In some cases they are so fragile that it has been necessary to find means to harden them before taking the wax impressions, which reproduce the forms of the originals and make it possible to determine many of them specifically. Some thirty distinct forms have been recognized, and the following notes on the various species will show the degree of certainty with which they have been determined and make clearer some obscure points of nomenclature.

AMMONITES (ÆGOCERAS) ANGULATUS, Schlotheim. (Pl. IX, fig. 1.)

1820. 'Die Petrefactenkunde' p. 70.
1870. Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 9.
1878–86. Wright, 'British Lias Ammonites' Monogr. Pal. Soc. p. 318 & pl. xiv, figs. 5–6.

Several more or less fragmentary casts of small shells, and one or two pieces of larger ones (about 80 mm. in diameter), are undoubtedly representatives of this species, which is the only form of ammonite recognized among these Arran fossils, and alone serves to indicate the horizon as that of the *Ammonites angulatus*-beds. Tate records this species as of rare occurrence in both *Ammonites angulatus*- and *Ammonites planorbis*-beds in the Belfast area.

AMBERLEYA ACUMINATA (Chapuis & Dewalque). (Pl. IX, fig. 2.)

1854. *Trochus acuminatus*, 'Descr. des Foss. des Terrains second. du Luxembourg' Mém. cour. Acad. Roy. Belg. vol. xxv, p. 82 & pl. xii, fig. 3.
1876. *Eucyclus acuminatus*, Tate & Blake, 'Yorkshire Lias' p. 346 & pl. x, fig. 20.

Specimens from the *Ammonites angulatus*-beds of Redcar were referred to this species by Messrs. Tate & Blake. One Arran specimen, which has the markings well preserved, agrees with the examples of this species in the Tate Collection, preserved in the Museum of Practical Geology. A portion of another specimen may belong here, or may perhaps be a piece of *Amberleya imbricata*.

CERITHIUM SEMELE (?) Martin. (Pl. IX, fig. 3.)

1860. 'Paléont. de l'Infra-Lias de la Côte-d'Or' Mém. Soc. Géol. France, ser. 2, vol. vii, p. 75 & pl. ii, figs. 8–10.
1870. Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 10.
1876. Tate & Blake, 'Yorkshire Lias' p. 350.

A specimen showing parts of three whorls agrees so nearly with Martin's figure of this species that it is referred to the same. The whorls are rounded, but there is a prominent, longitudinal, crenulated ridge along the middle: below this ridge are three, and above it two, less distinctly marked lines. The whole shell seems to have been ornamented by fine but distinct lines in the direction of the growth-lines. This species was recorded by Jules Martin from the lowermost Lias and *Avicula contorta*-zone of the Côte d'Or. Prof. Tate mentions it from the *Ammonites angulatus*- and *Amm. Bucklandi*-beds near Belfast, while he & Prof. Blake have found it at the same two horizons at Redcar.

CERITHIUM sp. (cf. *C. Falsani*, Dumortier).

A badly-preserved impression of a *Cerithium* about 14 mm. long and 4 mm. wide shows twelve whorls strongly angulated and nodular in the middle; there seem to be two fine longitudinal lines above, and two below, the angle. Indications of ridges in the direction of the lines of growth are to be traced on both the upper and under parts of each whorl. The ornamentation of this shell agrees most nearly with that of *C. Falsani* of Dumortier[1] which

[1] 'Etudes paléont. sur les Dépôts Jurass. du Bassin du Rhône,' vol. i (1864) p. 141 & pl. xxiii, fig. 7.

is from the zone of *Ammonites angulatus*, but our specimen is too imperfect for definite identification.

PLEUROTOMARIA TECTARIA, Tate. (Pl. IX, fig. 4.)

1870. 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 17.
1876. Tate & Blake, 'Yorkshire Lias' p. 338 & pl. ix, fig. 26.

A single specimen is referable to this species, but it is so like one of Prof. Tate's type-specimens, now in the Museum of Practical Geology, that I have no hesitation in referring it to the same species, which was in the first place found in the *Ammonites angulatus*-beds near Garron Point (Antrim), and afterwards recognized by Messrs. Tate & Blake in beds of the same age at Redcar (Yorkshire).

AVICULA LANCEOLATA, Sowerby. (Pl. IX, fig. 5.)

1826. 'Min. Conch.' pl. dxii, fig. 1.
Non *A. lanceolata*, Forbes, Quart. Journ. Geol. Soc. vol. i (1845) p. 247 & pl. iii, fig. 8.
Non *Gervillia lanceolata*, Goldfuss, 'Petrefacta Germaniæ' pt. ii (1834–40) p. 123 & pl. cxv, fig. 9.

There are two or three internal casts of a shell which agree so closely with Sowerby's *Avicula lanceolata* from the Lias of Lyme Regis that I cannot do otherwise than refer them to the same species. The most perfect specimen is a small one, 21 mm. long and 3½ mm. deep, including the wing at its widest part. It is markedly straight and almost parallel-sided. The umbo is nearly at the end of the shell. The cast of the straight hinge is marked by two longitudinal grooves, the inner one being the deepest. The posterior angle of the wing is rounded, and falls away backward with a convex outline. The comparative length of this shell suggests its reference to *Gervillia*; but there are no indications of the ligament-pits characteristic of that genus, and I am inclined therefore, for the present, to let this shell remain in the genus *Avicula*.

Prof. Tate, in his 'Irish Liassic Fossils' (p. 11), makes Sowerby's *A. lanceolata* synonymous with *Gervillia acuminata* of Terquem[1]; but with this identification I cannot agree; the latter species is a proportionately deeper shell, and much more curved.

PECTEN (CHLAMYS) SUBULATUS (?) Goldfuss. (Pl. IX, fig. 6.)

1834–40. 'Petrefacta Germaniæ' pt. ii, p. 73 & pl. xcviii, fig. 12.

Several internal casts of a smooth *Pecten* are provisionally placed in this species, as they seem most nearly to agree with Goldfuss's figures and description. Two of these are impressions of right valves, and show the shell to have been orbicular but somewhat oblique. The anterior wing of the right valve is large, with a deep byssal notch and a strongly crenulated ligamental margin. Below the wing the anterior margin of the shell is deeply concave. The umbo is acute and the posterior wing small. Specimens from the *Ammonites angulatus*-beds of Down Hatherley, which agree very closely with the Arran specimens, are in the Tate Collection, preserved in the Museum of Practical Geology. I am unable to

1 'Paléont. de la Province de Luxembourg & de Hettange' Mém. Soc. Géol. France, sér. 2, vol. v (1855) p. 316 & pl. xxi, fig. 15.

follow Messrs. Tate & Blake in regarding *P. subulatus*, Goldf., and *P. calvus*, Goldf., as one and the same species.

LIMA PECTINOIDES ? (Sowerby). (Pl. IX, fig. 7.)

1815. *Plagiostoma pectinoides*, 'Min. Conch.' pl. cxiii, fig. 4.
1870. *Lima pectinoides*, Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 11.
1876. Tate & Blake, 'Yorkshire Lias' p. 367.

Two or three specimens showing external characters apparently belong to this species, but as the hinge is not seen they may be *Lima*. *L. pectinoides* is very common in the Lower Lias.

LIMA SUCCINCTA (Schlotheim). (Pl. IX, fig. 8.)

1813. *Chamites*, 'Leonhard's Taschenbuch für die Mineralogie, &c.' vol. vii, p. 72 (figured in Knorr's 'Versteinerungen' suppl. iii, pl. v *d*, fig. 4).
1818. *Lima antiquata*, Sowerby, 'Min. Conch.' pl. ccxiv, fig. 2.
1870. Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 11.
1876. Tate & Blake, 'Yorkshire Lias' p. 365.

A portion of a *Lima*, showing the wings and having the irregular radiating ribs, with two or three smaller ribs between them, characteristic of *Lima antiquata*, Sow., is referred to this species, which is generally accepted as the same as *L. succincta* of Schlotheim. The characters are not well shown in the figure. This species is found in *Ammonites planorbis*- and *Amm. angulatus*-beds near Belfast and in similar, and possibly higher, beds in England.

INOCERAMUS (CRENATULA) sp.

Two or three imperfect internal casts appear to belong to this genus.

GRYPHÆA ARCUATA, Lamarck. (Pl. IX, fig. 9.)

1802. 'Système Anim. sans Vertèbres' p. 398.
1815. *Gryphæa incurva*, Sowerby, 'Min. Conch.' pl. cxii, figs. 1 & 2.
1870. *Ostrea arcuata*, Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 12.
1876. Tate & Blake, 'Yorkshire Lias' p. 359.

There are numerous internal and external casts of *Gryphæa*, and some at least of these, although small, are evidently *Gr. arcuata*. None of the examples attain to the size ordinarily met with in the Lower Lias, and it is worthy of note that Messrs. Tate & Blake always found this species dwarfed in the lower part of the *Ammonites angulatus*-beds at Redcar.

Gryphæa arcuata has a wide range in the Lower Lias; it has been recognized in the Antrim area in the *Ammonites angulatus*-beds, but is most common, there and elsewhere in Britain, in the *Amm. Bucklandi*-beds.

OSTREA IRREGULARIS (?) Quenstedt.

1858. 'Der Jura' p. 45 & pl. iii, fig. 15.
1870. Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 12.
1876. *Ostrea ungula*, Tate & Blake, 'Yorkshire Lias' p. 358.

Among the *Ostrea*-like internal casts there are one or two which have clearly been attached by a broad base to some ridged shell, and reproduce the ridges on their upper valves. Shells similar to

these are common in the Lower Lias, and have been referred to *O. irregularis*. This species has been recorded from the Rhætic, as well as from *Ammonites angulatus*- and *Amm. Bucklandi*-beds in the Belfast district, and from the last two horizons in Yorkshire.

MYOCONCHA PSILONOTI (?) Quenstedt. (Pl. IX, fig. 10.)

1858. 'Der Jura' p. 48 & pl. iv, fig. 15.
1870. Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 12.
1876. Tate & Blake, 'Yorkshire Lias' p. 393.

The impression of the middle portion of a *Myoconcha* showing the characteristic lines radiating from the umbo, agrees, so far as preserved, with *M. psilonoti*, which has been identified in the *Ammonites angulatus*-beds of Antrim and Yorkshire and from *Amm. Bucklandi*-beds in the latter area. Mr. Horace B. Woodward[1] notices the species from *Ammonites planorbis*-beds elsewhere in England.

NUCULA sp.

There are four or five internal casts of an oval *Nucula*, showing hinge-teeth and with prominent umbones, which certainly belong to this genus but may represent more than one species.

NUCULANA (LEDA) TATEI, Newton. (Pl. IX, fig. 12.)

1870. *Leda Renevieri*, Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 19 & pl. i, fig. 3.
1876. *Leda Renevierei*, Tate & Blake, 'Yorkshire Lias' p. 384 & pl. xi, fig. 4.
1858. *Nucula complanata β*, Quenstedt, 'Der Jura' p. 110 & pl. xiii, fig. 40 (*non* fig. 39).
1856. ? *Leda tenuistriata*, Piette, Bull. Soc. Géol. France, ser. 2, vol. xiii & pl. x, fig. 4, p. 206.
Non *Leda Renevieri*, Oppel, 'Die Juraformation' p. 95 (1856–58).

This form was originally described by Prof. Tate from Irish specimens, and was afterwards refigured in the 'Yorkshire Lias.' In both localities it occurs in *Ammonites angulatus*- and *Amm. Bucklandi*-beds. Tate's specimens are now in the Museum of Practical Geology, and show that both the figures are from imperfect specimens which must, when perfect, have had the rostrum longer than would appear from either the figures or descriptions. The upper margin of the rostrum is straight or slightly convex with external ridges, and it abuts against the umbones so sharply that it forms a distinct angle. The under margin of the rostrum is concave. These characters serve to separate the species from *Nucula complanata*, Goldfuss, to which imperfect specimens bear a close resemblance. Oppel states that the rostrum of his *Leda Renevieri* is shorter than in *Nucula complanata*: this, it seems to me, prevents the Irish specimens, figured by Prof. Tate, from being referred to the same species, and Messrs. Tate & Blake ('Yorkshire Lias' p. 384) were evidently uncertain as to the use of the name *Leda Renevieri*. This species is in all probability the form figured by Quenstedt (*op. cit.* pl. xiii, fig. 40) as *Nucula complanata β*. As a name is wanted for this *Leda*, it may be called *L. Tatei*.

[1] Mem. Geol. Surv. 'Jurassic Rocks of Britain, vol. iii (1893) Lias of England & Wales' p. 359.

There are six specimens from Arran which are referred to this species, as they undoubtedly agree with Prof. Tate's types. Most of them have the rostrum broken, but one remains perfect and is of remarkable length, although the shell is small.

NUCULANA sp. (cf. *Leda Quenstedti*, Tate). (Pl. IX, fig. 13.)

Two or three internal casts agree very nearly with the *Leda Quenstedti* of Prof. Tate,[1] but the rostral portions being less deep and the lower margin more curved, they cannot be placed definitely with that species.

Messrs. Tate & Blake[2] included *L. Quenstedti*, Tate, with *L. Galathea*, d'Orb., but the Yorkshire specimen, which they figure from the Middle Lias (*op. cit.* pl. xi, fig. 5), is certainly not the same form as that described from Antrim; and it is by no means sure that either of them is the *L. Galathea* of d'Orbigny or the *N. inflexa* of Quenstedt.

The specimen figured by Messrs. Tate & Blake is from the Middle Lias of Cleveland, and may be known as *Nuculana Galathea*, Tate & Blake (? d'Orb.). Other specimens in the Tate Collection in the Museum of Practical Geology, from the Lower Lias of Redcar and Marske, as well as some from Garron near Belfast, are clearly the form described and figured as *Leda Quenstedti* by Prof. Tate, and it is with these that the Arran specimens so nearly agree.

CARDINIA LISTERI (Sowerby). (Pl. IX, figs. 15 & 16.)

1818. *Unio Listeri*, 'Min. Conch.' pl. cliv, figs. 1, 3, & 4.

A portion of the exterior of a characteristically marked valve of this common shell, and an internal cast showing the hinge-teeth are good evidence of the presence of this species in Arran. *C. Listeri* has been found in *Ammonites planorbis*- and *Amm. angulatus*-beds near Belfast, and at these and higher horizons in England.

ASTARTE sp.

Several imperfect casts of a small *Astarte*, with coarse concentric ridges, cannot be specifically named.

CARDITA HEBERTI, Terquem. (Pl. IX, fig. 11.)

1855. 'Paléont. de la Prov. de Luxembourg & de Hettange' Mém. Soc. Géol. France, ser. 2, vol. v, p. 302 & pl. xx, fig. 10.

1870. Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 11.

1876. Tate & Blake, 'Yorkshire Lias' p. 388.

An internal cast, 11 mm. wide and about 9 mm. high, with crenulated margin, radiating costæ, and three concentric ridges, agrees better with the above species than with the *C. multicostata* of Phillips. Two less perfect specimens may likewise be referred to this species. *C. Heberti* has been recognized in the *Ammonites angulatus*-beds in the North of Ireland, and at the same horizon, as well as in *Amm. Bucklandi*-beds, in England.

[1] 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i (1870) pl. i, fig. 4.
[2] 'Yorkshire Lias' 1876, p. 383.

UNICARDIUM CARDIOIDES (Phillips). (Pl. IX, fig. 18.)

1829. *Corbula cardioides*, 'Geology of Yorkshire' pl. xiv, fig. 12.

Several examples of internal and external casts, all more or less imperfect, belong to this species, which is noticed by Prof. Tate from the zones of *Ammonites planorbis*, *Amm. angulatus*, and higher beds, in Antrim. It is found throughout the Lower and Middle Lias of England.

PROTOCARDIUM TRUNCATUM? (Sowerby).

1827. *Cardium truncatum*, 'Min. Conch.' pl. dliii, fig. 3.

An internal cast, which seems more likely to be the above species than *Protocardium Philippianum*, is thus recorded so that it may not be overlooked, but its identity is uncertain. *Pr. truncatum* occurs in the uppermost beds of the Lower Lias, but it is essentially a Middle Liassic form.

GONIOMYA sp. (cf. *G. rhombifera*, Goldfuss, and *G. sinemuriensis*, Oppel). (Pl. IX, fig. 17.)

A portion of a small and imperfect *Goniomya* may belong to one of the above species. It has the widely truncated angle in the middle of the valve similar to *G. rhombifera*, Goldf., of the Upper Lias, and, judging from the lines of growth, was a similarly short shell. *G. sinemuriensis* is said by Oppel[1] to be from the Lower Lias and to be like *G. rhombifera* in form, but with the anterior ribs irregular and meeting the cross-ribs at a more obtuse angle. Our specimen is too imperfect to show these characters properly, and on the whole it seems most like *G. rhombifera* from the Upper Lias; but as there is no evidence of Upper Liassic species among these Arran fossils, it is most likely that this *Goniomya* is the same as that found near Belfast in *Ammonites angulatus*-beds and referred by Prof. Tate[2] to *G. sinemuriensis* of Oppel.

PHOLADOMYA (?). (Pl. IX, fig. 19.)

Doubtfully represented by a single crushed internal cast.

TANCREDIA (?) PEACHI, sp. nov. (Pl. IX, fig. 20.)

Among these Arran Liassic fossils is one the generic position of which is still obscure. At first sight, it somewhat resembles a *Pleuromya* with well-marked concentric ridges; but a closer examination shows the deeper, and probably posterior, end to be truncated, and exhibiting a distinct groove extending from the umbonal region until it joins the lower margin at the posterior angle. About seventeen or eighteen angular concentric ridges may be counted, all of which end abruptly at the posterior groove. The shell has been flattened by pressure, and the depression seen towards the anterior and smaller end is to some extent, at least, due to this cause. Both the cast and mould are preserved, but a careful examination of them has revealed no indication of the shell having continued

[1] 'Die Juraformation, &c.' 1856–58, p. 95.

[2] Rep. Belfast Nat. Field Club, App. i (1870) p. 11.

beyond the groove. It seems probable, therefore, that the hinder end of the shell was gaping. The truncation and groove remind one strongly of the conditions found in *Tancredia*, and at present I know of no other genus that comes so near to this Arran shell.[1] Unfortunately there is no evidence as to the hinge-teeth; and no known species of *Tancredia* has such distinct and regular concentric ridges; but in the absence of definite characters it is proposed to place it provisionally in that genus, and in order to associate it with the name of my colleague, it may be called *Tancredia (?) Peachi*.

DITRUPA GLOBICEPS (Quenstedt). (Pl. IX, fig. 21.)

1858. *Serpula globiceps*, 'Der Jura' p. 111 & pl. xiii, fig. 21.
1870. *Serpula globiceps*, Tate, 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i, p. 13.
1876. *Ditrypa globiceps*, Tate & Blake, 'Yorkshire Lias' p. 438 & pl. xii, fig. 2.

A portion of a *Serpula*-like organism, with two distinct enlargements or rings, agrees so well with the above species that there is but little doubt as to its identity. This species has been found in *Ammonites angulatus*-beds near Belfast, and in Yorkshire.

DITRUPA sp.

One or two tapering and curved casts are almost certainly to be referred to this genus.

SERPULA sp.

Indications of *Serpula*-tubes are to be seen on several of the specimens.

PENTACRINUS BASALTIFORMIS (?) Miller. (Pl. IX, figs. 22 & 23.)

There are several specimens of basaltiform crinoid-stems: one showing four ossicles united, and others only the impression of the pentagonal and petaloid terminal face.

WOOD.

There is one specimen of wood, but it is in so friable a condition that nothing further can at present be said as to its structure.

List of Liassic Fossils from Arran.

* Found in the North-east of Ireland.

CEPHALOPODA.

**Ammonites (Ægoceras) angulatus*, Schlotheim.

GASTEROPODA.

Amberleya acuminata (Chapuis & Dewalque).
**Cerithium Semele (?)* Martin.
Cerithium sp. (cf. *C. Falsani*, Dumortier).
**Pleurotomaria tectaria*, Tate.

[1] [The Rev. J. F. Blake has called my attention to the resemblance which this specimen bears to certain *Aptychi*; and it may also be compared with Charles Moore's figure of *Pteromya Crowcombeia* (Quart. Journ. Geol. Soc. vol. xvii 1861, pl. xv, fig. 23), but it can hardly be referred to either of those forms.]

LAMELLIBRANCHIATA.

Arca (?). See Pl. IX, fig. 14.
Astarte sp.
Avicula lanceolata, Sowerby.
* *Cardinia Listeri* (Sowerby).
* *Cardita Heberti*, Terquem.
* *Goniomya* sp. (cf. *rhombifera*, Goldfuss, and *sinemuriensis*, Oppel).
* *Gryphæa arcuata*, Lamarck.
Inoceramus (*Crenatula*) sp.
* *Lima pectinoides* ? (Sowerby).
* *Lima succincta* (Schlotheim).
Modiola sp.
* *Myoconcha psilonoti* (?) Quenstedt.
Nucula sp. (two forms).
* *Nuculana* (*Leda*) *Tatei*, Newton (=*L. Renevieri*, Tate).
" " (cf. *L. Quenstedti*, Tate).
* *Ostrea irregularis* (?) Quenstedt.
Pecten (*Chlamys*) *subulatus* (?) Goldfuss.
Pholadomya (?).
Protocardium truncatum ? (Sowerby).
Tancredia (?) *Peachi* sp. nov.
* *Unicardium cardioides* (Phillips).

ANNELIDA.

Ditrupa globiceps (Quenstedt).
Ditrupa sp.
* *Serpula* sp.

CRINOIDEA.

Pentacrinus basaltiformis (?) Miller.

PLANTS.

Wood.

3. Cretaceous.

In June 1900, Mr. Peach detected foraminifera in cherty limestone in Ballymichael Glen (Arran), specimens of which were sent to me for examination. A further piece of cherty limestone (No. 9227), collected by Sir Archibald Geikie from Pigeon Cave (Arran), was received by me in October. Thin slices of the latter, examined microscopically, showed no definite organisms, yet the saccharoidal-crystalline condition and the faint traces left by organisms were so like certain sections of Antrim Chalk, with which they were compared, that there seemed little doubt as to the specimen being of like age. A collection of specimens of chert and limestone was made from Ballymichael Glen by Mr. Macconochie, which was also forwarded to me. Definite organisms could be seen in some of these with a lens, and several of the most promising were selected and sliced for microscopic examination.

This dark, grey, hard limestone, with angular fragments of white chert, is unlike what we commonly know as Chalk in the South of England; but it is not so unlike some of the hard Chalk of the North of Ireland. In some cases the siliceous portions are dark, and cannot be distinguished from ordinary Chalk-flints. The limestone

itself is sometimes, as in the first specimen examined, so much altered as to be saccharoidal in character, and with little or no trace of organic structure. Other specimens, however, have, under the microscope, all the appearance of Chalk, being very largely composed of foraminifera, and chiefly of the common *Globigerina*. Intermediate conditions of alteration are to be seen in other specimens, all of which may be matched by examples of Chalk from Antrim. Indeed, the similarity is so close that, even without further evidence, this Arran limestone would be referred to the Chalk; but, fortunately, certain organisms have been detected in both the limestone and chert which remove any doubt that may have existed.

Fossils from the Arran Chalk.

Inoceramus (piece of shell showing prisms).
Polyzoa (several specimens, perhaps *Entalophora* and *Esckarina*).
Echinoderm (fragments of).
Porosphæra globularis.
Hexactinellid sponge-fragments (? *Plocoscyphia*).
Tetractinellid and other spicules.
Globigerina cretacea (and other species).
Textularia, etc.

I desire to thank Dr. G. J. Hinde, F.R.S., for having kindly examined the macro- and microscopic specimens of Arran limestone and chert, and for allowing me to say that he endorses what has been stated above as to their being of Chalk age.

4. Conclusion.

The island of Arran is far from any locality where strata of Jurassic or Cretaceous age are now found in place, the nearest locality being in the North-east of Ireland, which is about 40 miles away, where there are strata corresponding in a remarkable degree with the masses met with in Arran.

The Secondary rocks of the North-east of Ireland, which had already been made known by Portlock,[1] were described more fully by Prof. Tate in 1863,[2] and in still greater detail in 1867.[3] In these papers it is shown that Rhætic beds, including the *Avicula contorta*-shales and the White Lias, rest upon older Triassic rocks and are overlain by Lower Lias, in which four distinct zones have been distinguished, namely, those of *Ammonites planorbis*, *Amm. angulatus*, *Amm. Bucklandi*, and *Belemnites acutus*. The uppermost of these zones is succeeded by Upper Cretaceous beds, Greensand, and hard Chalk,[4] and this again by basalt. Prof. Tate[5] has recorded undoubted Middle Liassic fossils from Ballintoy, but apparently from Drift, as hitherto they have not been found in place.

[1] 'Report on Geol. of Londonderry, &c.' 1843.
[2] Quart. Journ. Geol. Soc. vol. xx (1864) p. 103.
[3] *Ibid.* vol. xxiii (1867) p. 297. [4] *Ibid.* vol. xxi (1865) p. 15.
[5] *Ibid.* vol. xxvi (1870) p. 324.

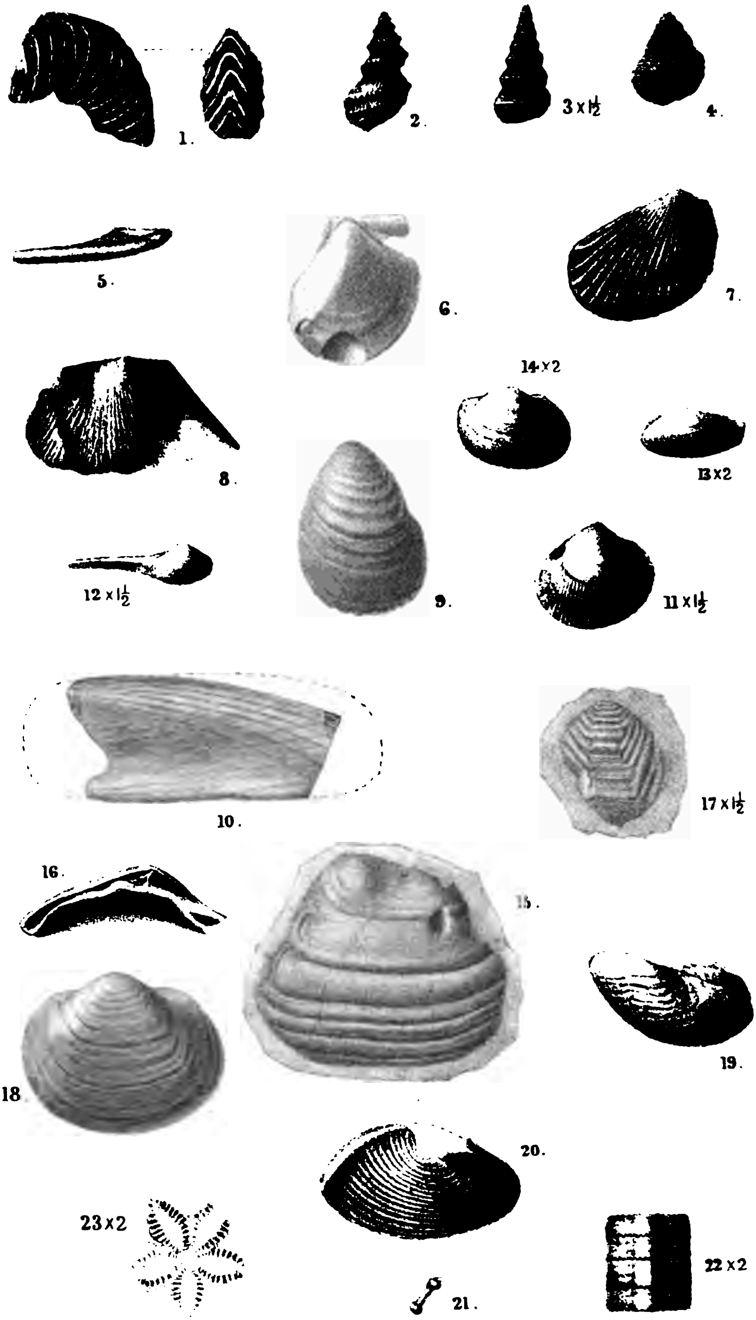
In 1870 Prof. Tate[1] published a revised list of the Liassic fossils of Ireland, and from this it will be seen that nearly all the Rhætic and Liassic species found in Arran have been met with likewise in the neighbourhood of Belfast. The Rhætic fossils of Arran indicate the former existence of strata corresponding with the *Avicula contorta*-shales, but at present there is nothing to represent the White Lias in particular.

That the Liassic fossils of Arran are from the earlier beds of that formation is evident, and broadly speaking, they are equivalent to the Lower Lias of the Belfast area; but I think that we may take another step with almost equal certainty. There seems no valid reason for supposing that the Liassic specimens hitherto found in Arran belong to more than one bed: for although some of the specimens are very friable and others tolerably hard, this is due to different degrees of decomposition. Now, among the fossils collected are several examples of *Ammonites angulatus*, while the characteristic ammonites of the *Amm. planorbis*- and *Amm. Bucklandi*-zones have not been met with; neither is there any fragment of a belemnite to indicate the 'Belemnite-shales.' It seems evident, therefore, that our Arran specimens belong to the *Ammonites angulatus*-zone. Many of the species range into higher or lower zones, but all of them have been met with in *Amm. angulatus*-beds elsewhere. Quite possibly representatives of the other Liassic zones of the Belfast area may yet be found in Arran; but, as it is the *Ammonites angulatus*-zone which attains the greatest thickness around Belfast, so it may have been in Arran. The similarity of the Chalk of Arran to that of Antrim has already been remarked upon.

But for the preservation of the remnants above described the presence of Mesozoic strata in Arran, other than the New Red rocks, would have been unknown, and their preservation is due to the accident of portions of the rocks having fallen into the neck of a volcano. Being thus removed to some distance below the surface of the country, they escaped the denuding influences that have so effectually removed the other parts of the parent rocks which there is every reason to believe formerly spread over the island of Arran, and were doubtless continuous to the south-west with the corresponding strata of the North-east of Ireland: forming also a link between that district and the Liassic and Cretaceous areas of the Western Islands of Scotland and the small Liassic district near Carlisle. The still further extension of Cretaceous deposits in Scotland is indicated by the well-known remains of Greensand age near Moorseat (Aberdeenshire).

The Liassic and Cretaceous rocks of the Western Isles of Scotland are perhaps 100 miles north-west of Arran, and have been noticed in part by the earlier writers mentioned in the more recent works of Sir Archibald Geikie,[2] Thomas Wright,[3] and Prof. Judd[4]; but

[1] 'Irish Liassic Fossils' Rep. Belfast Nat. Field Club, App. i (1870).
[2] Quart. Journ. Geol. Soc. vol. xiv (1858) p. 1. [3] *Ibid.* p. 24.
[4] *Ibid.* vol. xxxiv (1878) p. 696.



A.T.Holl... lith. Mintern Bros. imp.

LIASSIC FOSSILS FROM ARRAN.

the fossils of the Lower Lias which have been recorded from that area do not correspond so nearly with the Arran specimens as do those from the neighbourhood of Belfast. The zone of *Avicula contorta* does not seem to be distinctly developed in the Western Isles, according to Prof. Judd, although he had seen some indications of its presence, and only last year, under Mr. Horace B. Woodward's directions, some obscure fossils were obtained from Skye which it is thought may represent these beds.[1] The numerous other horizons of Jurassic strata described in the Western Isles, having no representatives among the Arran fossils, need be no further alluded to. Above them, however, are Cretaceous rocks which Prof. Judd refers to the Lower, Middle, and Upper Chalk: the last-named horizon being that of *Belemnitella mucronata*, and apparently corresponding with the White Limestone of Antrim. If this correlation be correct, it seems highly probable that the Arran limestone will prove to be on the same horizon.

EXPLANATION OF PLATE IX.

Lower Liassic fossils from Ballymichael Glen, near Shiskine (Arran). The figures are of the natural size, except figs. 3, 11, 12, 13, 14, 17, 22, & 23.

Fig. 1. *Ammonites (Ægoceras) angulatus*, Schloth. (M. 2971. E.)
2. *Amberleya acuminata* (Chap. & Dewal.). (M. 2966. E.)
3. *Cerithium Semele (?)* Martin. × 1½. (P. 240.)
4. *Pleurotomaria tectaria*, Tate. (M. 2967. E.)
5. *Avicula lanceolata*, Sow. (M. 2981. E.)
6. *Pecten (Chlamys) subulatus (?)* Goldf. (M. 2911. E.)
7. *Lima pectinoides?* (Sow.). (M. 2913. E.)
8. *Lima succincta* (Schloth.). (M. 2917. E.)
9. *Gryphæa arcuata*, Lam. (M. 2859. E.)
10. *Myoconcha psilonoti (?)* Quenst. (M. 2911. E.)
11. *Cardita Heberti*, Terquem. × 1½. (M. 2924. E.)
12. *Nuculana (Leda) Tatei*, Newton. × 1½. (M. 2980. E.)
13. *Nuculana*, sp. × 2 (cf. *Leda Quenstedti*, Tate). (M. 2962. E.)
14. *Arca (?)*. × 2. (M. 2939. E.)
15. *Cardinia Listeri* (Sow.). (M. 2907. E.)
16. Do. do. (showing hinge). (M. 2896. E.)
17. *Goniomya*, sp. × 1⅓ (cf. *G. rhombifera* and *G. sinemuriensis*, Oppel). (M. 2899. E.)
18. *Unicardium cardioides* (Phillips). (M. 2912. E.)
19. *Pholadomya (?)*. (M. 2926. E.)
20. *Tancredia (?) Peachi*, sp. nov. (M. 2921. E.)
21. *Ditrupa globiceps* (Quenst.). (P. 232.)
22. *Pentacrinus basaltiformis (?)* Miller. × 2. (P. 246.)
23. Do. do. × 2 (petaloid end of ossicle). (M. 2982. E.)

[The numerals in parentheses are the registration-numbers of the specimens preserved in the Geological Survey Collections.]

DISCUSSION.

Mr. H. B. WOODWARD remarked that the occurrence of Rhætic fossils in Scotland was first noticed by Charles Moore, from specimens obtained in the Drift at Linksfield, near Elgin. He (the speaker) had mapped 'passage-beds' between Trias and Lias in

[1] 'Summary of Progress of the Geological Survey for 1899' p. 132.

Raasay and Skye, but had found no recognizable Rhætic species; and although Mr. Macconochie and Mr. Tait had since met with much better specimens in Skye, no distinctive Rhætic species could with certainty be identified. It was therefore highly satisfactory that characteristic fossils from this formation had now been discovered in Arran, in beds which, judging from their extent, could not be far removed from the parent source.

Mr. G. W. Lamplugh inquired whether, besides the blocks that had fallen into the vent from higher levels, there were any sedimentary masses raised from lower horizons by the volcanic forces.

The Rev. J. F. Blake and Prof. W. W. Watts also spoke.

Sir Archibald Geikie replied, on behalf of the Authors of the paper, to some of the questions raised in the discussion. He remarked that there were two points of more especial interest in the discovery which had that evening been announced to the Society—the proof supplied as to the age of the youngest eruptive rocks of Arran, and the evidence furnished of the stupendous denudation of the country since the time of the Chalk. With regard to the first of these points, it would be remembered that early in the last century Macculloch had shown that, as no fragments of the Arran granite were to be found in the surrounding Red Sandstones, that rock was presumably younger than these strata. As far back as 1873 the speaker, after a prolonged study of the igneous masses of Skye and Mull, had expressed the opinion that the Arran granite would probably be found to belong to the great Tertiary Volcanic Series of the North of Ireland and West of Scotland. The recent observations of Messrs. Peach & Gunn, and the confirmatory determinations by Mr. Newton, put the matter beyond all further dispute. The Red Sandstones of the southern half of the island are now seen to be unquestionably Triassic, and they are further shown to have been overspread with Rhætic, Liassic, and Upper Cretaceous strata. As the volcanic vent broke through the youngest of these formations, its appearance must have been later than the Chalk; and thus the age of the whole complex assemblage of younger eruptive masses in Arran, which, including the granite, present so close a petrographical resemblance to those of Mull and Skye, is definitely fixed by palæontological evidence. Of the fragmental materials that fill this great vent, no doubt the main part was shot up from below, but, as in some of the Carboniferous rocks of Scotland, there is evidence that large cakes and masses of the surface-rocks of the country tumbled into the volcanic orifice from above. To this fortunate accident we owe the proof that the Mesozoic Series of Antrim once stretched north-eastward into the basin of the Clyde.

The second feature of surpassing interest in the paper was to be found in the further light now thrown on the history of the denudation of the region. It was reasonable to suppose that at the close of the deposition of the Antrim and Arran Chalk the surface of that formation, whether as sea-floor or as land, stretched as a tolerably level platform, as far at least as the hills that surround the

basin of the Clyde. Since that time the whole of the existing topography has been carved out. So vast has been the denudation, that the Chalk and the Lias have been entirely stripped off the country, as they have been likewise in Antrim, save where protected by the overlying basalt-plateau; while the much thicker Triassic sandstones and marls have been reduced in area to what is seen of them in Arran, and what may still lie concealed under the Firth of Clyde.

The island of Arran has long been famous for the variety of its geological structure, but the recent detailed work of the speaker's colleagues of the Geological Survey has shown this variety to be far more wonderful than had ever before been imagined. In particular, its volcanic history has been found by Mr. Gunn to be especially full, from the time of the presumably Arenig rocks, on through the Lower Old Red Sandstone and the Carboniferous Series, to the complex assemblage of Tertiary masses. The geological survey of the island is now completed, and has had a most appropriate consummation in the discovery described in the present paper. Sir Archibald was sure that the Fellows would agree with him in thinking that Mr. Peach and Mr. Gunn were to be congratulated upon the skill and insight with which they had worked out a piece of difficult ground; that Mr. Macconochie deserved hearty thanks for the intelligence and enthusiasm which had led to the discovery of the fossiliferous masses in the vent; and that to no fitter hands than those of Mr. Newton could the fossils have been entrusted, which have revealed the former presence of so many Mesozoic horizons in the South of Scotland.

16. Recent Geological Changes *in* Northern *and* Central Asia. By Prof. George Frederick Wright, F.G.S.A. (Communicated by the President. Read March 6th, 1901.)

There are so many points of resemblance between Northern and Eastern America and the corresponding areas of Asia that one would naturally expect to find that the Glacial history of the two regions had been somewhat similar. In North America the evidence is abundant and unmistakable, that in post-Tertiary times Glacial ice extended along the Atlantic coast southward from Labrador and the Hudson-Bay region as far as New York City in lat. 41°, and in the Mississippi Valley to Carbondale in Southern Illinois, about lat. 38°. North of an irregular line connecting these points the whole country was, at a very recent period, covered with Glacial ice as deep as that which mantles Greenland at the present time. In all, about 4,000,000 square miles were brought under the direct influence of Glacial ice in America.

Being familiar with nearly the whole of this North American field, and somewhat so with the glaciated portions of Europe, I set out, a little more than a year ago, in company with my son, Mr. Frederick B. Wright, to examine those portions of the Asiatic Continent which most nearly correspond in general superficial conditions to the glaciated portions of America. Sailing from San Francisco in February 1900, we spent six weeks in Japan, and satisfied ourselves that lofty as the mountains are, there have never been extensive glaciers among those on Nippon, the largest of the islands. From the verbal reports made to us by Prof. Jimbo, of the University of Tokyo, it seems equally clear that the more northern island of Yesso shows no signs of general glaciation, though it extends from lat. 42° N. to lat. 45°.

From Japan we went to Peking, and on the 8th of May set out for Kalgan, 150 miles inland, on the Mongolian frontier, spending a week in an excursion along the border of the Mongolian plateau and the mountainous region to the north-east. The general elevation here is about 5000 feet, while many peaks rise up to heights considerably greater, and the latitude corresponds nearly to that of New York. But we observed nowhere any signs whatever of Glacial action.

This whole region through which we rode on muleback was, however, covered with lœss, and is in large part the section of country from which Baron Ferdinand von Richthofen drew his powerful arguments for the agency of the wind in the distribution of the lœss. In the storms which we encountered, we had abundant opportunity of witnessing the power of wind in transporting, not only dust, but sand and gravel. For a whole half-day before reaching Kalgan we faced a storm in one of the valleys, when we could not see half way across the road on account of the dust which filled the air, while

our faces were stung by the larger grains of sand which continually dashed against them. On the edge of the Mongolian plateau we frequently saw, and occasionally encountered, vast inverted cones of dust which with a swift whirling movement were travelling over the country.

The actual agency of wind in the deposition of the lœss is evident throughout the mountainous tract to the east of the border of the high plateau. We crossed over three of these mountain-ridges, each rising 5000 feet above the sea, with intervening valleys about 3000 feet lower, and were everywhere struck with the way in which the lœss had especially accumulated on the south-east side of the mountains, which was in general the lee side. The resemblance to immense snow-drifts was remarkable. Many villages were built in these huge drifts, the houses being simple excavations, sometimes one storey above another, in this peculiar deposit. Shiwontse, the celebrated Belgian Mission Station, with a population of 2000, consists almost entirely of houses constructed after this manner.

Still there were other areas of lœss so large and so level that wind would seem incompetent to produce them. These are frequent in the mountain-valleys traversed, but more especially in the extensive plain of lœss which extends from the Gulf of Pe Chi Li, 25 miles past Peking, to the Naukau Pass. This plain rises gradually to the west, until, on approaching the mountains, there is much coarse material interstratified with it. Indeed, the mountain-streams are marked by enormous old deltas at their mouths, largely composed of lœss. That in front of the small Nankau River is more than 100 feet above the plain where the stream debouches into it, and is distinctly perceptible for a distance of 5 miles. Pebbles of considerable size were frequent 3 and 4 miles from the head of the delta, and its surface sloped at the rate of 100 feet per mile. In the mountainous region the occurrence of strata of gravel and pebbles in the lœss was so frequent as constantly to attract attention. It seems therefore necessary to invoke both wind and water, in order fully to explain the distribution of that formation.

But in any event the deposition of the lœss over Eastern China took place at a very recent geological date. Its era is to be reckoned in thousands and tens of thousands of years rather than in periods of hundreds of thousands and millions. The period of the lœss in China corresponds roughly with that of the continental glaciers in Europe and North America. This is evident from the rapidity of present erosion, as compared with present subaerial deposition. On approaching the western shore of the Yellow Sea one crosses, 40 miles out, a sharply-cut line on one side of which is clear sea-water, and on the other water turbid with the silt gathered by the rivers from the lœss-fields of China. The head of the Gulf of Pe Chi Li has been filled in by sediment from the Peiho for 40 miles since 200 B.C. The land has encroached upon the sea below Tientsin for 18 miles since 500 A.D. Everywhere

in the interior the lœss is being washed away by the streams much faster than it is deposited by the wind. Long, deep, impassable channels in it frequently obstruct the traveller in his endeavour to cross any level section of it. Everywhere in the mountainous region it is clear that the rock-erosion had been mainly accomplished before the deposition of the lœss, and that already a large fraction of this has been removed.

Finding no signs of Glacial action in South-eastern Mongolia, we returned to Peking, and left for Tientsin at noon on May 26th. On the 27th the revolution broke out, and the railway was destroyed, so that if we had started a day later we should have been cooped up in Peking during the summer, instead of pursuing our geological studies. All unconscious of the impending troubles, we went to Port Arthur, to make a section from that point along the line of the Chinese Eastern Railway to Harbin, on the Sungari River. This is a distance of about 750 miles through the heart of Manchuria, and would take us through the cuttings in a newly-constructed railway across seven degrees of latitude. Of this distance 550 miles was travelled on construction-trains, and 200 in Chinese carts. The entire region traversed consists of a valley 50 miles or more in width. Everywhere this is deeply covered with alluvium, while the slopes both up and away from the centre are exceedingly gentle. For the most part the sediment seemed purely residual, or such as had been brought into position by the streams now in possession of the field. At Kwan Chentse, 100 miles south of the Sungari River, the watershed between that and the Laoho, whose valley we had been ascending for 300 miles, was less than 500 feet above sea-level, and was approached by a gradient so gentle that we could not detect it as we drove over it. Specimens of soil from freshly-dug wells showed evidences of fine stratification to a depth of 50 feet. The lines of drainage from here to the Sungari River were exceedingly sluggish, and the small stream which we followed for most of the way occupied a valley several miles wide, covered with peat-bogs. This sluggish drainage characterizes all the tributaries of the Sungari River in the central part of Manchuria. The troughs of all the streams in that region are very old, and show a recent depression of land resulting in an extensive filling up of the channels. Wells at Harbin brought up fine alluvium at a depth of 80 feet.

The Amur has many resemblances to the St. Lawrence, the two rivers being in nearly the same latitude, and both emptying into ice-clogged seas above the 50th parallel. In America we have abundant evidence that the St. Lawrence was dammed up by Glacial ice, so that the drainage was temporarily turned into the Champlain and Mississippi Valleys. But no evidence of this sort could be found in Eastern Asia, though we searched diligently for it along the southern watersheds of the Sungari and Ussuri Rivers. The conclusion seems indubitable that there was no general glaciation

of the lower Amur Valley south of the 53rd parallel. There are, however, abundant indications that the whole drainage of the lower Amur basin has been obstructed by a recent differential subsidence, reducing the gradient to a very low degree. The entire descent from Blagovestshensk to the sea, a distance of about 1200 miles, is less than 300 feet. Nevertheless, it has in this part of its course cut a channel across the Bureya Mountains down to base-level, while both above and below this range the bordering flood-plains and low-level expanses of alluvium extend as far as the eye can reach. We drove for 80 miles over these plains below the mouth of the Zeya River, but there was nothing anywhere to be seen except rich, rolling, grassy (but nearly timberless) prairie-land. In the vicinity of Kavarosk and Blagovestshensk extensive thin gravel-deposits are spread over wide level areas 200 or 300 feet above the river.

From Blagovestshensk to Chita, a distance of 1200 miles, the river-channel consists of a deep trench cut by the stream across mountains and through broad tablelands. A very pronounced rock-shelf or terrace, 300 or 400 feet above the present level, is almost everywhere to be seen. Chita, in lat. 52° N., is between 2000 and 3000 feet above the sea, and lies at the mouth of a valley coming down from the vast Vitim Plateau, which is about 5000 feet above the sea. Here, if anywhere, we expected to find marks of former glaciation; but we were disappointed. The whole aspect of the country shows the effect of long-continued subaerial erosion. There is no transported material away from the immediate vicinity of the streams. The rocks are everywhere deeply disintegrated by subaerial agencies, and the slopes of the sides of the valleys are very gentle, showing the influence of long and uninterrupted subaerial erosion.

On the other side of the Vitim Plateau, about 500 miles farther west, the lower part of the Uda Valley exhibits an equal absence of glacial marks, though at one point about 3 miles above Verkne Udinsk there were some granite-boulders in a clay-deposit which had much the appearance of Glacial Till. But, as there were outcrops of the granite within a few hundred yards of the place, it would manifestly be unsafe to base any conclusions upon them. There was an equal absence of glacial signs for the 200 miles which we followed down the Kilok River, which, like the Uda, has cut a wide, deep channel across nearly the whole width of the Vitim Plateau.

Lake Baikal presents some interesting problems in regard to recent geological changes. It is completely surrounded by mountains, rising from 3000 to 4000 feet above it, except at one narrow depression through which the Angara River carries off its surplus waters. Its surface is 1560 feet above the sea, but in its southern portion it is 4500 feet deep. Its recent origin can be inferred from the fact, that it is not filled with the sediment brought into it by the Selenga and other rivers, all of which have in their long course

through the Central plateau eroded valleys several miles wide and of great depth, having evidently, in the period of their history, brought down sediment enough to have filled the depression many times over. It is significant also that the lake is now inhabited by a species of seal closely allied to those found in the Caspian Sea.

Passing over the low-lying region west of the Yenisei River, we ascended the Irtish River from Omsk to Semipalatinsk, and travelled by tarantass to Tashkend, 1200 miles along the base of the high mountains which form the border of the Central Asiatic Plateau on the north-west. Our route took us through Sergiopol and south of Lake Balkash, through Kopal, Vernoe, Tokmak, Auleata, Chimkent, Tashkend, Samarkand, and Merv to the Caspian Sea. As far as Tashkend the Ala Tau and Alexandrovsky Mountains rose immediately to the south of our route, to heights frequently reaching 15,000 feet. The general elevation of the road was between 2000 and 3000 feet, while the latitude is about that of Switzerland. But while local glaciers can be frequently seen in the higher portions of the chain, and the water of nearly all the larger mountain-streams is to some extent turbid with glacier-detritus, there are no signs that glaciers ever deployed out upon the plains as they did from the Alps during the Glacial Period.

For 600 miles, however, between Vernoe and Samarkand, our route lay over a broad terrace of lœss, in many places certainly 100 feet thick. This constitutes the fertile irrigated belt of territory which gives importance to Turkestan, and furnishes valuable data for the interpretation of the problems of post-Pliocene geological movements. The belt of lœss is of varying width, and merges gradually into the drifting sands of the deserts to the north. It is present in special abundance in the valleys of the Ili, the Chu, the Sur Daria, and the Amu Daria Rivers. It is on diametrically the opposite side of the Central Asiatic Plateau from the similar deposits in China, while they are so persistent, so continuous, and so extensive, that nothing but a wide-spread submergence of the region to the extent of about 3000 feet would seem to explain the phenomena.

Nor is contributory evidence of such a submergence wanting. Lake Balkash, about 1000 feet above the sea, has no outlet; yet I was told by the geologists in St. Petersburg that its water is nearly fresh. This indicates that a comparatively short time has elapsed since it discharged its waters into some lower basin. The Aral Sea, also, has no outlet, and its waters are only brackish. No long time can have elapsed since it discharged into the Caspian Sea through the well-marked dry channel that can be easily traced between the two basins. The saltness of the Caspian Sea is also only about one third that of the ocean. The innumerable dried-up lakes which had no extensive tributaries are now salt-beds.

All this indicates very recent physical changes in the region, of a nature to have great influence upon the climate. Enclosed basins such as these would naturally contain water much salter than that of the ocean. It is evident, therefore, that upon the emergence of

the area from below sea-level the rainfall for a considerable period must have been so great, that all these basins overflowed their watersheds until they became freshened; while, since the evaporation has exceeded the precipitation, time enough has not elapsed for salt to accumulate to any great extent. It is difficult to explain this upon any theory, except that of a recent and gradual elevation of the region, which left under water a sufficient extent of the low-lying portions to secure the increased precipitation implied. This points to a deposition of the lœss by water rather than by wind, for the æolian hypothesis implies a dry condition where certainly there was just the opposite.

At Trebizond, on the Black Sea, we found the clearest direct evidence of this great continental subsidence. Behind that city a prominent mass of volcanic rock rises precipitously to a height of 850 feet. Clinging to the sides of this, at an elevation of 650 feet, is a deposit of fresh-looking beach-gravel, about 100 feet thick, and extending for nearly half a mile. Scattered patches of gravel extend up to 750 feet, but none could be found higher. This deposit was subsequent to the entire rock-erosion of the region, and certainly belongs to very recent geological times. A subsidence to that extent would submerge all Southern Russia, and help to account for the extensive lœss-plains which form the most striking characteristic of that region.

Another piece of direct evidence of such a subsidence in Southern Russia was found in the lower part of the Dariel Pass, on the north side of the Caucasus Mountains. A careful examination of this pass shows that it was never occupied by a glacier. Yet for several miles below the narrowest part of the pass, where the elevation is 3000 or 4000 feet above the sea, the valley, after the rock-erosion had proceeded to its present extent, was re-filled with clay, sand, and gravel to a depth of 300 or 400 feet. It is noteworthy that these deposits are finest near the bottom. The facts would not necessitate a general depression to sea-level, but only a differential subsidence, increasing towards the axis of the range. But, as there is free drainage to the north, and no chance for local obstruction of the channel, extensive recent changes of level must have taken place in that region.

We found that the geologists in St. Petersburg agreed with the conclusion to which we had unwillingly come, that there was no general glaciation of Siberia south of lat. 56° N., and that however much the wind had to do with the lœss-deposits of China, it was not adequate to account for the lœss of Turkestan and Russia. This gives special significance to the recent discovery of Palæolithic implements beneath the lœss at Kiev, a discovery described by Prof. Armashevsky in a pamphlet prepared for the VIIth International Geological Congress in 1897. The whole situation was explained to us, in November 1900, by him on the spot. The general level of

the surface is here 630 feet above the sea. The Dnieper has cut a trough in this plain to a depth of 350 feet, exposing the strata in a very convenient manner. The lœss constitutes the upper 50 feet of the deposits. The stone-implements were found below the lœss, at a total depth of 53 feet. Thus it appears that the continental submergence which aided in the wide distribution of the lœss was subsequent to the appearance of man, and so another chapter is added to those which connect the ancient history of the human race with the more recent phases of the geological story.

If, in conclusion, we are permitted to speculate upon the causes of the contrast between the post-Tertiary conditions of Asia and those of North America, we may assume that the absence of continental glaciers in Asia may be partly due to those permanent climatic conditions which render so much of Central Asia almost rainless, and all of Northern Asia a comparatively dry region. North of the 40th parallel the annual precipitation is everywhere less than 20 inches in Asia, except over a comparatively narrow belt along the sea-coast in the extreme east. But I am inclined to think that difference of elevation may have been the cause. In America there is abundant evidence that the Glacial Period was coincident with a continental elevation of 2000 or 3000 feet. If, as seems likely, the depression of the land in Asia was coincident with the elevation in America, this may well be the cause of the absence of glaciers which we have found to characterize Northern Asia during post-Tertiary times.

Discussion.

Mr. F. B. Wright, Jr., and Mr. G. W. Lamplugh spoke.

The Author remarked that fossils of any sort were very rare in the lœss everywhere. In America the land-shells found in it indicated moister conditions than those now prevailing; but, as water freely percolates through the lœss, it is likely that by this means most fossils would be dissolved. This may be the cause of the numerous calcareous concretions which abound in the formation. It is fairly certain that the lœss in America was distributed by water-action: the bluffs of lœss, for example, at Vicksburg, in the middle of the Mississippi Valley, could hardly have been deposited by wind.

17. *On the* Character *of the* Upper Coal-Measures *of* North Staffordshire, Denbighshire, South Staffordshire, *and* Nottinghamshire; *and* their Relation *to the* Productive Series. By Walcot Gibson, Esq., F.G.S.[1] (Read March 20th, 1901.)

Contents.

I. Introduction.

The productive measures in the Midlands are succeeded by a considerable thickness of strata, barren of workable seams of coal. The study of these higher strata has, in comparison with that given to the coal-bearing portion of the Carboniferous, been neglected, though they early attracted the attention of Murchison,[2] Prestwich,[3] and Phillips.[4] By these and subsequent observers, the presence of thin bands of impure limestone with *Spirorbis* was considered to characterize the series. It has also been generally recognized that while the predominating colour of the productive series is grey, that of the overlying barren series is red; but, with the exception of Beete Jukes[5] and D. C. Davies,[6] no definite sequence has been even suggested. Fresh interest was given to the study of these strata by the discovery that the fauna and flora of the immediately overlying red beds, or 'Salopian Permian,' possessed a Coal-Measure facies, and that it would be more natural to include them in the Carboniferous system. Recently it has been stated, in two papers,[7] that the higher Coal-Measures are strongly unconformable to the underlying productive series.

The object of this paper is to show that in four widely-separated areas a definite lithological sequence may be distinguished in the higher Coal-Measures; that the relation of the upper to the

[1] Communicated by permission of the Director of H.M. Geological Survey.

[2] 'Silurian System' 1839, pp. 81 *et seqq.*

[3] 'On the Geology of Coalbrookdale' Trans. Geol. Soc. ser. 2, vol. v (1840) pp. 428 *et seqq.*

[4] Mem. Geol. Surv. vol. ii (1848) pt. i.

[5] Mem. Geol. Surv. 'South Staffordshire Coalfield' 2nd ed. (1859).

[6] Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 10.

[7] T. T. Groom 'On the Geological Structure of Portions of the Malvern & Abberley Hills' Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 138–95, & W. J. Clarke 'The Unconformity in the Coal-Measures of the Shropshire Coalfields' *ibid.* vol. lvii (1901) pp. 86–95.

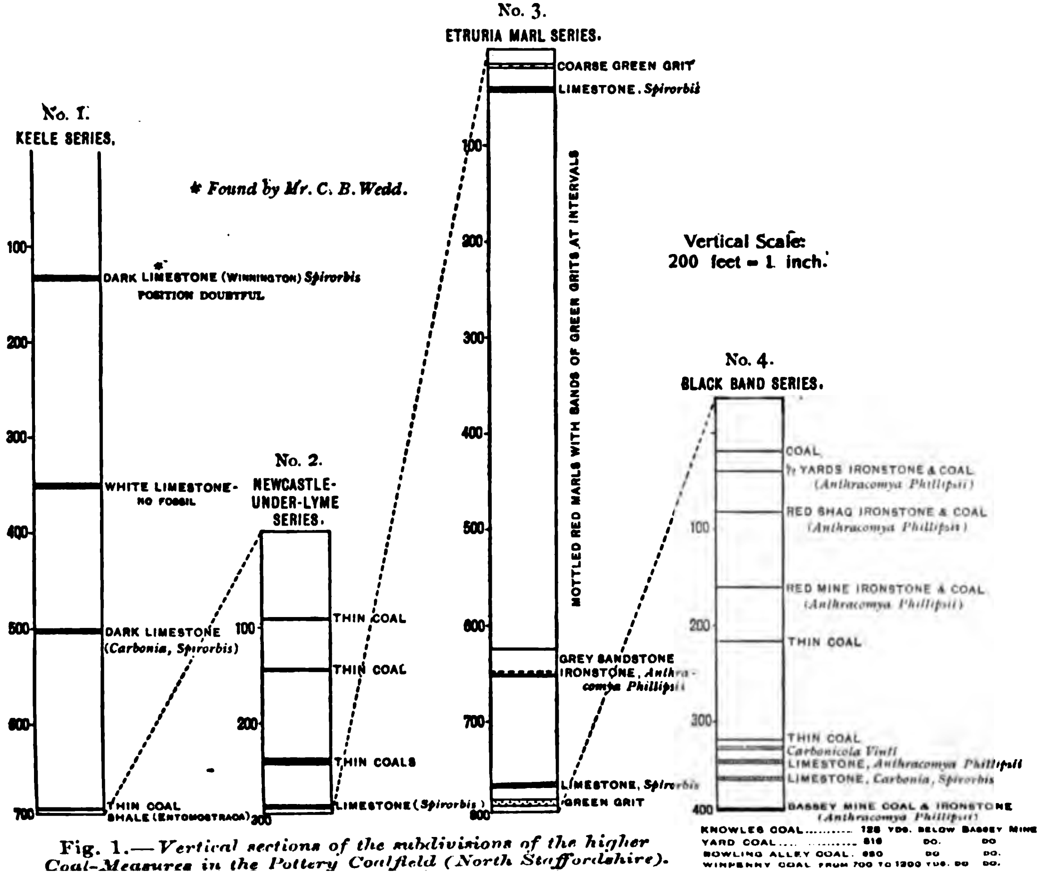


Fig. 1.—*Vertical sections of the subdivisions of the higher Coal-Measures in the Pottery Coalfield (North Staffordshire).*

productive series in North Staffordshire is one of strict conformity; and that the evidence is in favour of the post-Carboniferous age of the chief movements which have affected the Midland Coalfields.

The Pottery Coalfield of North Staffordshire, comprising one of these areas, has been surveyed by Mr. Wedd and myself. The southern portion of the South Staffordshire Coalfield, described in this paper, had been partly mapped by me in connection with the field-class of the Birmingham University, and the typical sections were revisited last year. With the object of comparing the upper series in Denbighshire with that of North Staffordshire, the sections exposed in the Dee Valley to the east of Chirk, and between Ruabon and Wrexham, were visited last year. I have also had the opportunity of examining, from time to time, the cores from the boring at Thurgarton (Nottinghamshire).

II. North Staffordshire.

Before dealing with the Upper Coal-Measures of the Pottery Coalfield it will be necessary to say a few words about the productive series. For convenience of description, the base may be taken at the Winpenny Coal, the lowest workable seam, and the summit at the Bassey Mine Coal. Grey is the prevalent colour; but on two horizons at least, notably above the Yard Coal (516 yards below the Bassey Mine), and again a short distance above the Knowles or Winghay Coal (128 yards below the Bassey Mine), red sandstones and shales from 30 to 50 feet thick are developed, and can be traced throughout the eastern district. At Western Sprink, red shales and calcareous nodules above the Yard Coal have yielded to Mr. John Ward a marine fauna including cephalopoda and brachiopoda, and also *Carbonia Rankiniana*, an entomostracan common at several horizons in the higher Coal-Measures. At other stages, but mainly associated with bands of ironstone, entomostraca and *Spirorbis* are common, and at Adderley Green Mr. Ward pointed out to me a grey limestone with *Spirorbis* as low down as the Bowling Alley Coal (167 yards below the Yard Coal). It is seen, therefore, that red strata and bands of limestone with *Spirorbis* are not confined to the higher barren measures.

The change from the grey measures, with numerous and thick seams of coal and a prolific fauna, into the barren (mainly red) strata above the Bassey Mine Coal, is very gradual. The coal-seams deteriorate slowly in quality and thickness, and the fauna becomes poorer in number and species as the sequence is traced upward. This is particularly the case with the mollusca, which become rare in the upper part of the productive measures, and thus foreshadow the sparse fauna of the barren series. The character, fossil contents, and thickness of the beds succeeding the Bassey Mine Coal are shown in descending order in the appended table (p. 254).

TABLE SHEWING THE SUBDIVISIONS OF THE HIGHER COAL-MEASURES IN NORTH STAFFORDSHIRE, ETC.

Name of Subdivision.	*Characters.*	*Organic Contents.*	*Thickness.*
KEELE SERIES.	Red and purple sandstones and marls. Occasional seams of coal. Thin black and grey limestones and subordinate bands of grey sandstone and shale. Base, entomostracan shale.	*Neuropteris Scheuchzeri, N. rarinervis, N. Miltoni, Lepidodendron, Calamites undulata, C. Cistii, Lepidophyllum lanceolatum, Sphenophyllum, Cordaites.* *Spirorbis, Carbonia Wardiana, C. pungens, C. scalpellus, C. Rankiniana, Elonichthys, Diplodus gibbosus.*	Over 700 feet at Keele Park. Summit nowhere visible.
NEWCASTLE-UNDER-LYME SERIES.	Grey sandstones and shales with four thin seams of coal. Base, entomostracan limestone.	*Alethopteris aquilina, A. lonchitica, Calamocladus equisetiformis, Lepidodendron Sternbergii, L. variabilis, Mariopteris muricata, Neuropteris ovata, N. gigantea, Pecopteris arborescens, Stigmaria ficoides, Calamites approximatus, Lepidostrobus variabilis, Sigillaria Brardii, Rhabdocarpus sulcatus.* *Spirorbis, Carbonia Wardiana, Anthraoomya calcifera.*	300 feet.
ETRURIA MARL SERIES.	Chiefly mottled red and purple marls and clays. Thin bands of green grit very characteristic. Limestone-bands near the summit and base. Lenticular mass of grey sandstone overlying a laminated ironstone, and thin coal 150 feet above the base (Chesterton only). Base, often a greenish fine-grained sandstone.	Plant-remains undetermined. *Spirorbis, Carbonia, Anthracomya Phillipsii.*	800 to 1100 feet.
BLACK-BAND SERIES.	Grey sandstones, marls, and clays. Some lenticular bands of grey grit and slightly-mottled marls. Numerous thin seams of coal and Black-Band ironstones. Thin bands of limestone throughout the series, one of which is constant at 36 to 40 feet above the base. Base, Bassey Mine Coal.	*Calamites varians, C. Suckowii, Mariopteris muricata, Triletes.* *Spirorbis, Carbonia, Anthracomya Phillipsii, Carbonicola (Anthracosia) Vinti, Megalichthys Hibbertii, Cœlacanthus lepturus, Diplodus gibbosus, Ctenodus cristatus.*	300 to 450 feet.

For the plants, see R. Kidston, Trans. Roy. Soc. Edin. vol. xxxvi (1892). For the other fossils, see J. Ward, Trans. North Staffs. Inst. Min. & Mech. Eng. vol. x (1890), & Proc. North Staffs. Field Club, vol. xxxiv (1900) pp. 87–92; Wheelton Hind, Monogr. Pal. Soc. vol. xlix (1895), & Quart. Journ. Geol. Soc. vol. lv (1899) pp. 365–68.

A description of these subdivisions has appeared elsewhere,[1] and need not be repeated. The main characters are given in the table, while the position of the various bands of limestone and Black-Band ironstones are shown in vertical sections Nos. 1–4, fig. 1, p. 252. I will confine myself, therefore, to such evidence as the district affords, in settling the question of the relation of the subdivisions one to the other and to the productive series.

Let us first consider the relation of the subdivisions one to the other.

Relation of the Etruria Marl Series to the Black-Band Series.

The base of the Etruria Marls is generally, but not invariably, a greenish-yellow grit. When this is absent, red marls rest directly on the top of the Black-Band Series. Grits of a kindred character are of frequent occurrence throughout the subdivision, and are persistently and strongly developed near the summit, where they are much coarser than those at the base. Their presence, therefore, does not mark any particular line of erosion. That the basal grits do not indicate a discordance is shown by the fact that they always occur a few feet above a Black-Band ironstone known as the Top Red Mine or Half-Yards, that is, subjected to the law of thickening and thinning of the strata to be mentioned later on (p. 258); they are developed at the same vertical distance above the Bassey Mine Coal or base of the Upper Measures. At one locality, Chesterton, about 150 feet up in red marls, a thin band of Black-Band ironstone, overlain by grey grit, is developed. The ironstone contains *Anthracomya Phillipsii* in abundance, a fossil very common in the Black-Band Series. The Etruria Marls also contain thin limestones, with entomostraca similar to those found in the Black-Band Series. It is, moreover, noticeable that bands of red marl are present in the middle and towards the summit of the Black-Band Series (Hampton's Marl-Pit, Shelton, Cannon Street, Ladyswell, Longton Hall), thus showing the oncoming of the conditions under which the Etruria Marls were deposited. The Etruria Marls are, therefore, stratigraphically and palæontologically allied to the Black-Band Series.

Relation of the Newcastle-under-Lyme Series to the Etruria Marls.

The Newcastle-under-Lyme Series can be clearly demonstrated to be conformable to the Etruria Marls by the limestone at its base invariably occupying a position 30 to 50 feet above a band of limestone that occurs near the summit of the Etruria Marls. Instances of the gradual passage of the red Etruria Marls into the grey shales

[1] 'Summary of Progress of the Geological Survey for 1898–1899' Proc. North Staffs. Field Club, vol. xxxiv (1900) pp. 95–97.

and sandstones of the Newcastle-under-Lyme Series can be seen in many localities in the district, and is illustrated by the following section, measured in a marl-pit near Longport Railway-station:—

		Feet.	Inches.
Newcastle-under-Lyme Series.	Yellow flags and shales	20	0
	Yellow shales, with fish-scales	0	6
	Red shales.—*Carbonia*	1	6
	Black shales.—*Carbonia*, fish-scales	0	8
	Red shales	2	0
	Red limestone.—*Carbonia*, fish-remains	1	0
	Yellow shales	0	8
	Blue limestone.—*Anthracomya calcifera*	0	8
	Yellow shales	1	0
Etruria Marls.	Purple marls	35	0
	Greenish-yellow grit (base not seen)	+ 2	0
	Brecciated limestone	1	0
	Red marl.		

Relation of the Keele Series to the Underlying Strata.

The Keele Series includes the red sandstones and marls formerly classed with the North Staffordshire Permian.

The Coal-Measure character of the flora, the occurrence of a thin seam of coal, and the presence of entomostracan and *Spirorbis*-limestone, suggest that the Keele Beds belong to the Carboniferous system. It is, therefore, of considerable importance to determine their stratigraphical relationship to the Newcastle-under-Lyme Series, which has always been regarded as a member of the Carboniferous.

The Keele red sandstones and marls occupy a wide area on the south and south-west of the Pottery Coalfield. They are always underlain by the full thickness of the Newcastle-under-Lyme Series, and are faulted and folded in a similar manner and to the same extent. They also contain grey sandstones and shales resembling the Newcastle-under-Lyme strata, as well as thin bands of mottled red marls, like those of the Etruria Marls, as may be seen in the railway-cutting at Keele Park.

It is apparent, therefore, that a close stratigraphical and lithological relationship exists between the Keele Series and the underlying strata, and that they are conformable one to the other. The contrary opinion has been held, and it has been stated[1] that, from Audley to Blurton, 'the Permian red sandstones and marls rest with a slight discordance upon the Upper Coal-Measures.' It is true that at Blurton Tileries, near Longton, the red sandstones of the Keele Beds are in juxtaposition with the Etruria Marls and basal beds of the Newcastle-under-Lyme Series. In the absence of faulting this would imply a great unconformity; for 1 mile to the south in

[1] 'The Triassic & Permian Rocks of the Midland Counties of England Mem. Geol. Surv. 1869, p. 24.

the Newstead boring, and near Dresden, 600 yards to the east, and at Hanford, 1¼ miles to the west, the Keele Series lies on tho normal thickness of Newcastle beds. The junction, however, has been proved by actual trenching to be a fault, agreeing in direction with one proved underground to the east.

Another instance where the Keele Beds are represented[1] as being unconformable to the underlying strata, is near Halmerend Station, where the North Staffordshire branch-railway cuts through some red sandstones dipping at a high angle to the west. These red strata lithologically resemble Keele Sandstone, but it can be shown that they lie in the productive measures. Their exact position, however, is uncertain, owing to the confusion existing as to the correlation and identification of the higher coal-seams of the productive series in this district. But from information kindly placed at my disposal by Mr. Rigby, the Apedale Coal & Iron Company, and the Madeley & Leycett Coal Company, it is evident that these red sandstones lie conformably on the ordinary Coal-Measures at the horizon of either the New Mine Coal or the Great Row Coal: that is to say, they are Middle Coal-Measure sandstones of a red colour. If they rest on the New Mine Coal they lie 1800 feet below the base of the Keele Series, and may be correlated with the similar sandstones developed at or near this horizon in the Middle Coal-Measures to the east. If they lie on the Great Row Coal, they are about 1700 feet below the base of the Keele Series.

The supposition that these red sandstones are of Keele age would necessitate the existence of a great unconformity confined to this locality; for, 100 yards east of the railway-cutting, the Etruria Marls crop out and cover a considerable extent of ground on the north, while on the south the Black-Band Series, Etruria Marls, and Newcastle-under-Lyme Series are developed in normal sequence.

The presence of Etruria Marls east and north of the railway-cutting is due to a fault with a considerable westerly downthrow, proved in the Minnie sinking near Halmerend Station, and in the underground workings farther north.

Relation of the Black-Band Series to the Productive Measures.

The various subdivisions of the higher Coal-Measures having been shown to be mutually conformable, the relation of the Black-Band Series to the productive measures will now be investigated.

As already mentioned (p. 253), the rich pelecypodan fauna of the productive measures slowly dwindled away in the upper portion of the series, as the conditions represented by the deposition of grey sandstones, shales, clays, and numerous seams of coal changed to those suitable for the laying down of the great thickness of red sandstones, marls, and clays forming the higher Coal-Measures.

[1] Geol. Surv. Map, Sheet 73, N.E.

An example of this gradual palæontological change is illustrated by the genus *Anthracomya*. Throughout the lower part of the productive measures large species of this genus are abundant. Above the Knowles Coal (p. 253) the large robust forms are replaced by the much smaller and thin-valved species *Anthracomya Phillipsii*, This fossil occurs sparingly in the Knowles ironstone.[1] It is found in some black shales below the Little Row Coal (see the measured section, below), and becomes very abundant in all the Black-Band ironstones of the Black-Band Series.

While the palæontological evidence thus records slowly-changing conditions, the transition is no less clearly demonstrated by stratigraphical data. Thus the Bassey Mine Coal always overlies the Little Row Coal and the Peacock Coal (a seam easily identified throughout the district), and these in turn rest upon strata containing recognized coal-seams. The strata above and below the Bassey Mine are identical in character, as shown in the following section measured in the marl-pit near Cobridge Railway-station :—

		Feet.	Inches.
Black-Band Series.	White clay	5	0
	Limestone.—*Spirorbis, Carbonia*	1	2
	Nodular grey marls	15	0
	Grey marl	5	0
	Dark shale	0	6
	Grey marl	22	0
	Bassey Mine Ironstone.—*Anthracomya Phillipsii*	6	0
	Bassey Mine Coal	2	0
Upper part of Productive Series.	Grey marls	13	0
	Little Row Coal	1	6
	Black shale	1	6
	Grey marl	9	0
	Black shale.—*Anthracomya Phillipsii*	0	4
	Grey marl	10	0
	Grey grit	1	0
	Grey marl	17	0
	Peacock Coal.		

Further proof of the close relationship between the barren and the productive series exists in the simultaneous gradual increase or decrease in thickness as the two groups are traced from south to north on the one hand, or from east to west on the other. This is clearly demonstrated on a sheet of vertical sections illustrative of the coalfield which will be published in the course of the present year.[2] It may be stated here that the Black-Band Series at Shelton is 150 yards thick; while at Apedale, 4 miles to the west, the thickness is only 90 yards. At Shelton the vertical distance between the Bassey Mine Coal and Eight Feet Banbury (Cockshead Coal) is over 1100 yards; while at Apedale the distance between those two seams is reduced to 650 yards.

If there was a break between the upper and the productive series it must have been of short duration, otherwise we are forced to

[1] Wheelton Hind, Monogr. Pal. Soc. vol. xlix (1895) p. 121.
[2] Geol. Surv. Vert. Sect., Sheet 86.

suppose that exactly the same law of sedimentation recommenced after the break as had been in operation before it.

The Black-Band Series is thus seen to be palæontologically and lithologically allied to the productive series: it also obeys the same law of sedimentation as that under which the productive measures were deposited. It is therefore not surprising to find that it shares in all the faulting and folding which affect the Carboniferous strata in North Staffordshire. Without unduly forestalling the Geological Survey memoir which will give the details of the structure, I may say that every fault and all the synclines and anticlines affect the higher measures as much as the underlying series.

On the other hand, the map of the North Staffordshire Coalfield to be published shortly brings out very clearly the great unconformity between the Trias and the Carboniferous, and shows that many of the faults which affect the latter do not affect the Trias, or do so in a lesser degree. It is, therefore, evident that the chief movements which have resulted in the tectonic structure of the North Staffordshire Coalfield took place in the great interval of time marked by the hiatus between the Trias and the Carboniferous systems.

The Red Colour shown to be Original.

As long as the Keele Sandstones and Marls were considered to be of Permian age, the red colour was regarded as original, but when it became evident that they belonged to the Carboniferous, the question arose whether the colour might not be due to subsequent staining. It will, therefore, not be out of place to say a few words on this subject.

The great thickness of the Keele Series is in itself a strong argument against the colour being due to subsequent staining. Also on the view of after-staining it is difficult to understand why at Blurton, where the Keele Sandstone is faulted against the basal beds of the Newcastle Series (p. 256), the former is of a deep red colour and the latter pale grey or white, since both are equally open and porous rocks. The fact that entomostracan limestones, or red shales with entomostraca, invariably accompany the red colour, shows that this marks conditions of deposition, and that the red coloration is original.

Summary.

To summarize briefly the results obtained in North Staffordshire: The upper barren Coal-Measures of North Staffordshire are capable of a fourfold subdivision, the groups representing a definite sequence of red and grey strata. Thin bands of limestone with *Spirorbis* and entomostraca are developed throughout, and certain of them occupy definite and constant positions. Though these attain their maximum development in the barren series, they are not unknown in the productive measures. Red strata are at their maximum thickness in the higher barren measures, but, although

subordinate, they also occur in the productive series. There is no sign of a break between the productive and the barren series; on the contrary, they are closely allied palæontologically, lithologically, and stratigraphically in this region. The chief movements are pre-Triassic and post-Carboniferous.

The sequence of the higher Coal-Measures in Denbighshire, South Staffordshire, and Nottinghamshire will now be briefly described. No attempt will be made to recognize the Black-Band Series, as, in the absence of limestone and bands of Black-Band ironstone, the strata are indistinguishable from the productive series. Nor will the relation of the higher Coal-Measures to the underlying strata be touched upon, as this can only be satisfactorily settled by systematic mapping and a more prolonged examination than I have been able to make.

III. Denbighshire.

The Coal-Measures of North Staffordshire appear again from under the cover of Triassic rocks in Denbighshire. During two visits to the ground round Ruabon, Wrexham, and to the east of Chirk, I was able to find the representatives of the Keele, Newcastle, and Etruria-Marl subdivisions, thus confirming the opinion as to the close connection of the Pottery Coalfield with that of Denbighshire.

Red marls are well shown in the banks of the Dee and its tributary, the Ceriog, to the east of Chirk. In Pentre-isaf Ravine, on the northern bank of the Dee, the grey limestone with *Spirorbis* and *Carbonia*, as described by Mr. D. C. Davies, is visible: it evidently lies near the base of the marls. Lower down in the ravine, but higher up in the marls, a bluish-grey limestone with *Spirorbis* and *Carbonia* was found. In the banks of the Ceriog bands of green grits lying in red marls are seen near the junction of Glyn Morlas with the Ceriog. Mr. D. C. Davies has accurately noted the presence of these bands, here and elsewhere in the neighbourhood. He states[1] that 'the pebbles and fragments consist chiefly of Lower or Cambro-Silurian rocks with their imbedded quartz, felspar, greenstone, and porphyry, together with fragments of Wenlock Shale and Carboniferous Limestone.' The increased coarseness of the bands of grit compared with those occurring in the Etruria Marls of North Staffordshire is explained by the fact that the Denbighshire Coalfield lies near the margin of the coal-basin, Silurian strata cropping out 5 miles to the west.

The upper portions of the marls are exposed in Glyn Morlas, and in a small ravine near Pentre they are seen passing up into a series of grey sandstones and marls. At the junction a thin band of reddish limestone, containing *Carbonia* and *Anthracomya calcifera*, is developed. This makes it almost certain that the underlying marls represent the Etruria Marls of North Staffordshire, and that the overlying grey sandstones are the equivalents of the Newcastle-under-Lyme Series. This identification is confirmed on finding the

[1] Quart. Journ. Geol. Soc. vol. xxxiii (1877) p. 11.

grey series overlain near the bridge at Pen-y-lan by red sandstones and marls lithologically similar to the Keele Series. As in North Staffordshire, these red measures have been hitherto included in the Permian.

It will be seen (vertical section No. 2, p. 252) that the Newcastle-under-Lyme subdivision contains four thin seams of coal. In the Ifton-Heath shafts (Davies, *op. cit.*), east of Glyn Morlas, three coals were intersected. The chief seam, consisting of 4 feet 9 inches of coal and 1 foot 11 inches of parting, is known as the Morlas Main Coal, and is overlain by a strong rock, Coedyrallt Rock. The Morlas Main Coal is underlain by grey shales and sandstones with two coal-seams. No mention is made of a limestone-band with entomostraca. In Glyn Morlas the limestone occurs 20 feet below a seam of coal underlain by grey sandstone. If this corresponds to the lowest seam recorded in the Ifton-Heath section, the total thickness of grey rocks above the red marls of Glyn Morlas and Pentre-isaf Ravine would be between 330 and 350 feet. The underlying red marls appear from Mr. Davies's account to be about 840 feet thick. Red marls, similar to those found in Glyn Morlas and the Ceriog valley, are worked for bricks by the Ruabon Colliery Company, 1 mile north of Ruabon. Good sections of the red sandstones and marls, similar to those seen at Pen-y-lan, are afforded by the large brick-pits at Pentre, south-east of Wrexham.

The close lithological resemblance and the similarity of organic contents of the strata just described with the Keele, Newcastle-under-Lyme, and Etruria-Marl subdivisions of the higher Coal-Measures in North Staffordshire renders it certain that the same conditions marked the close of the Coal-Measure period in Denbighshire as in the Pottery Coalfield. As equivalent terms for the subdivisions in North Staffordshire, I would suggest Wrexham Red Sandstones and Marls, Coedyrallt Series, and Ruabon Marls.

Whatever may be the relation in Denbighshire of the higher measures to the productive series, it is of importance to note that the upper series rests on some 800 feet of grey strata containing numerous workable seams of coal.

IV. South Staffordshire.

The succession above the Upper Sulphur Coal, 250 feet above the well-known Thick Coal of South Staffordshire, was given by Beete Jukes[1] in ascending sequence as :—Red Coal-Measure Clays 300 feet, Halesowen Sandstone Series 400 feet, the latter being overlain by the red sandstones and marls of Hunnington. The description of these subdivisions given by Jukes recalls forcibly the Denbighshire and North Staffordshire sequence.

While mapping, under the direction of Prof. Lapworth, the area of Carboniferous rocks south of Halesowen, I found a blue limestone with *Spirorbis* near the summit of the Halesowen Group.

[1] Mem. Geol. Surv. 'South Staffordshire Coalfield' 2nd ed. (1859) pp. 28–31.

The limestone is best seen in Illey Brook near the old mill. Further examination of the area last year made it clear that the Red Coal-Measure Clays of Jukes consisted near Old Hill of red marls lithologically similar to the Etruria Marls, and that they also contained the characteristic bands of green grits. Some of these are coarse breccias, and contain large angular fragments of Lickey quartzite, the nearest outcrop of which is 6 miles south-south-east of Old Hill.

The Halesowen Sandstone group, which succeeds the Red Coal-Measure Clays, consists of yellow and grey sandstones and a few thin coals. Its junction with the Red Clays was not actually seen; but in an old marl-pit near Halesowen, situated at or near the junction, fragments were found of a calcareous rock in which entomostraca are visible. I learned that these fragments had been thrown out from a well close by.

The olive-coloured sandstones and shales, with the *Spirorbis*-limestone of Illey Brook, which lie at the top of the Halesowen Series, are separately grouped by Prof. Lapworth.[1] They are succeeded by red sandstones and marls identical with the Keele Series, and can be examined in the streams flowing northward from the Clent Hills.

The North Staffordshire sequence of higher Coal-Measures is thus again repeated in all essential characters round the southern margin of the South Staffordshire Coalfield. So far as is yet known, the limestone at the top of the Halesowen Group, which is to be compared with the Newcastle-under-Lyme Series, is confined to South Staffordshire. On the other hand, no entomostracan limestones have yet been recorded from the Red Coal-Measure Clays. In all other respects the North Staffordshire and South Staffordshire sequences are identical.

The South Staffordshire Coalfield is situated near the southern margin of the basin; we therefore find that, as the rim is approached, the upper measures overlap all the other divisions, including the Thick Coal Group, till near Rubery the Halesowen Sandstones rest upon the Silurian and Cambrian rocks of the Lickey Hills.

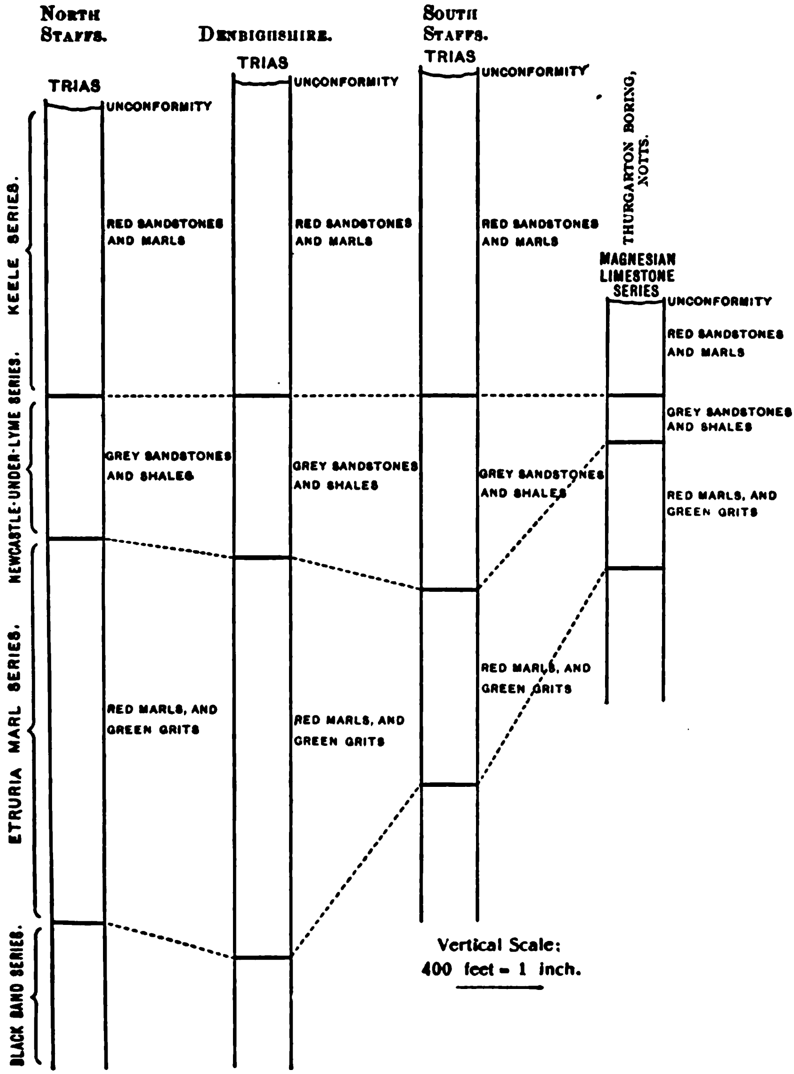
V. Nottinghamshire.

In an examination of the cores from Thurgarton, 10 miles north-east of Nottingham, the North Staffordshire sequence was again recognized. I am permitted to give the following abstract account:—

Underlying the Marl Slate with *Productus horridus*, and separated from it by a band of breccia, 188 feet of red sandstone and marls were pierced. The red marls contained the remains of plants, which have been determined by Mr. Kidston as *Neuropteris rarinervis*, *Pecopteris Miltoni*, *Cordaites* sp., and *Sphenophyllum* sp. In colour, texture, and composition, the sandstones and marls resemble the

[1] 'Sketch of the Geology of the Birmingham District' Proc. Geol. Assoc. vol. xv (1898) p. 366.

Fig. 2.—*Comparative sections of the higher Coal-Measures in North Staffordshire, South Staffordshire, Denbighshire, and Nottinghamshire.*



Keele Beds. They are underlain by grey sandstones and shales, containing at least one seam of coal. After passing through 91 feet of these grey measures, red marls of the Etruria-Marl type and containing the characteristic bands of green grit were proved for a thickness of 257 feet. Below these ordinary grey Coal-Measures were entered.

At or near the junction of the grey beds with the underlying red clays, the cores contained calcareous nodules, but no entomostraca were found in them. At the junction of the grey with the overlying red beds, the cores consisted of black shales with entomostraca similar to those found at the junction of the Keele and Newcastle Series in the Newstead boring near Trentham (North Staffordshire). How much of the North Staffordshire sequence is present at Thurgarton it is not safe to say, for undetected faults may have been passed through. It is certain, however, that the Keele, Newcastle-under-Lyme, and Etruria-Marl Series exist at Thurgarton to the east of the Pennine Chain, and that the chief Pennine movements are therefore of post-higher Coal-Measure age.

VI. General Summary.

By means of the type established in North Staffordshire it has been shown that a similar set of conditions prevailed over a wide area in the Midlands during the closing stages of the Coal-Measure period. In North Staffordshire, where the relation of the different groups of the Coal-Measures has been studied in detail, no break has been detected in the Coal-Measure sequence. On the contrary, one stage merges imperceptibly into the other. In the remaining areas dealt with in this paper the higher Coal-Measures are invariably underlain, except near the margin of the basin where overlap takes place, by ordinary Coal-Measures with coal-seams. It is, therefore, evident that the higher Coal-Measures were deposited in one basin, which included at least North Staffordshire, Denbighshire, South Staffordshire, and Nottinghamshire; and that whatever movements occurred were of a local, and not regional, character.

From descriptions and accounts of other areas it would appear that the higher series is present in Lancashire [1], Cumberland [2], Anglesey [3], Shropshire [4], Worcestershire [5], and Warwickshire [6].[1] In all these areas, excepting perhaps Cumberland and Lancashire, the Keele Series is represented, and corresponds to the 'Salopian Permian' of Prof. Hull. In all of them much work remains to be done, before the important questions can be answered as to the distribution, thickness, and character of the higher Coal-Measures and their relation to the productive series.

[1] The numerals in brackets refer to the appended Bibliographical List.

VII. Bibliographical List.

[1] E. W. Binney. 'The Upper Coal-Measures of England & Scotland' Trans. Manch. Geol. Soc. vol. vi (1866) p. 38.
E. Hull. 'The Geology of the Country around Oldham' Mem. Geol. Surv. 1864.
E. Hull. 'The Triassic & Permian Rocks of the Midland Counties of England' Mem. Geol. Surv. 1869.
E. Hull & A. Strahan. 'Geology of the Country around Prescot' Mem. Geol. Surv. 3rd ed. (1882) pp. 44–48.
A. Strahan. 'The Geology of the Neighbourhoods of Flint, Mold, & Ruthin' Mem. Geol. Surv. Supplement (1898).
[2] J. D. Kendall. 'The Whitehaven Sandstone Series' Trans. Fed. Inst. Min. Eng. vol. x (1896) pp. 202–24.
T. V. Holmes. 'Notes on the Whitehaven Sandstone' Geol. Mag. 1896, p. 405.
A. Strahan. Ann. Rep. Geol. Surv. for 1894, p. 272.
[3] A. Ramsay. 'The Geology of North Wales' Mem. Geol. Surv. 2nd ed. (1881) pp. 261–68.
[4] R. I. Murchison. 'Silurian System' 1839, p. 83.
J. Prestwich. 'On the Geology of Coalbrookdale' Trans. Geol. Soc. ser. 2, vol. v (1840) pp. 428 *et seqq.*
D. C. Davies. 'The North Wales & Shrewsbury Coalfields' Quart. Journ. Geol. Soc. vol. xli (1885) Proc. p. 107.
M. W. T. Scott. 'On the Symon Fault in the Coalbrookdale Coalfield' Quart. Journ. Geol. Soc. vol. xvii (1861) p. 457.
D. Jones. 'Denudation of the Coalbrookdale Coalfield' Geol. Mag. 1871, pp. 200–208.
Id. 'The Structure of the Forest of Wyre Coalfield' Trans. Fed. Inst. Min. Eng. vol. vii (1894) pp. 287–300 & 577; also vol. viii (1895) p. 356.
W. J. Clarke. 'The Unconformity in the Coal-Measures of the Shropshire Coalfields' Quart. Journ. Geol. Soc. vol. lvii (1901) pp. 86–95.
[5] T. C. Cantrill. 'On *Spirorbis*-limestone, &c. in the "Permian" Rocks of Wyre Forest' Quart. Journ. Geol. Soc. vol. li (1895) pp. 528–48.
Id. 'Geology of the Wyre Forest Coalfield,' Kidderminster, 1895.
[6] H. H. Howell. 'The Geology of the Warwickshire Coalfield' Mem. Geol. Surv. 1859.
C. Fox-Strangways & W. W. Watts. 'The Geology of the Country between Atherstone & Charnwood Forest' Mem. Geol. Surv. 1900, p. 28.

Appendix.

Microscopic slides of specimens of the green grits characteristic of the Etruria Marls in North Staffordshire, and of their representatives at Thurgarton and in South Staffordshire, have been examined by Mr. George Barrow, F.G.S. He states that:—

'the rocks resemble one another in the fact that they are built up of fragments mostly of igneous origin, set in a matrix which has resulted from the complete decomposition of still smaller fragments of similar material. Whether the rocks themselves are true ashes, or are derived from the comminution of lavas, it is not possible to decide with certainty. No fragments with hour-glass form have been recognized, but the finer material is so completely decomposed that such may well have been once present. If they be not true ashes, the material of which these rocks are composed has not travelled far.'

Discussion.

Mr. W. J. Clarke congratulated the Author on his excellent paper. He considered that the Author's correlation of the North Staffordshire and Denbighshire Upper Coal-Measures was correct, and that when the officers of the Geological Survey dealt with the Wrexham district they would find still further confirmation in the many

new exposures laid open there recently. Referring to the green rocks made up of igneous material, he asked whether they could be correlated with the strata proved in the Sealands borehole near Chester, which was found to contain resorted, disintegrated granite-débris.

Mr. T. C. CANTRILL expressed the belief that it would ultimately be found that the sequence of higher Coal-Measures established in North Staffordshire—or at least some green grits similar to those of the Etruria Marls—were to some extent represented in Wyre Forest also. However this might be, we now knew that the lowest division of the so-called 'Permian' of Wyre Forest contains a *Spirorbis*-limestone band and a thin coal, and in all respects resembles the Keele Beds of North Staffordshire. With regard to Warwickshire, it was now still more certain that there is no perceptible break at the base of the 'Permian.' The supposed outlier of these rocks, formerly represented on the Geological Survey map west of Polesworth as having overstepped a considerable thickness of the Coal-Measures, has lately been found by Mr. Fox-Strangways to be a sandstone within the ordinary Coal-Measures, and not 'Permian' at all.

Prof. T. T. GROOM said that the palæontological evidence adduced by the Author in proof of his views seemed to be less convincing than the stratigraphical. But even if the Coal-Measures proved to be a conformable series in the areas described by the Author, there might be unconformity elsewhere. There was, indeed, much evidence of the existence of at least one unconformity in the Coal-Measures over a wide area, both at home and abroad. Portions of the English Midlands might well be exceptional in this respect, as had been suggested on a former occasion. The Author had correlated his 'Keele Series' with the 'Salopian type' of Prof. Hull's 'Permian.' If this correlation were correct, the circumstance that the 'trappoid breccia' of the latter contained fragments of Carboniferous Limestone and sandstone afforded additional proof of unconformity in the Carboniferous Series, in areas which were adjacent to those described by the Author, and in which unconformity had been deduced on stratigraphical grounds.

Mr. A. STRAHAN replied to Mr. Clarke that the rock found in the Sealands boring was composed of granitic material disintegrated and resorted, and was likely to be recognizable at the outcrop, but that it did not resemble the green rocks.

Mr. G. BARROW and Prof. W. W. WATTS also spoke.

The Author said, in reply, that he was pleased to hear that Mr. Clarke recognized the North Staffordshire sequence in Denbighshire, and that Prof. Watts found the representative of the Etruria Marls in East Warwickshire. No attempt had been made in the paper to discuss the problems raised by Prof. Groom.

18. *The* IGNEOUS ROCKS *and* ASSOCIATED SEDIMENTARY BEDS *of the* TORTWORTH INLIER. By Prof. CONWY LLOYD MORGAN, F.R.S., F.G.S., and Prof. SIDNEY HUGH REYNOLDS, M.A., F.G.S. (Read April 3rd, 1901.)

[PLATES X & XI.]

CONTENTS.

I. INTRODUCTION.

THE Silurian rocks of the Tortworth district in Southern Gloucestershire present several features of geological interest. Lying to the north of the horseshoe ridge of Carboniferous Limestone, which forms the rim of the Bristol Coalfield, they share in the synclinal disposition of the Palæozoic strata. They underlie the attenuated Old Red Sandstone, which in this district is not more than some 200 or 300 feet thick; but the exact relation of Silurian to Old Red is nowhere clearly seen. The strata include beds of Ludlow, of Wenlock, and of Upper Llandovery age, the last-named being originally regarded as Caradoc. The chief points of interest are: (1) the remarkable attenuation of the upper strata, the Ludlow Beds not exceeding 100 feet in thickness, and the Wenlock attaining a thickness of at most 700 feet, probably less; (2) the limited number of fossils recorded; and (3) the occurrence of igneous rocks interbedded with the Upper Llandovery strata, and passing up to, or perhaps just into, the Lower Wenlock Beds. It is with these igneous rocks and their relation to the sedimentary beds that this paper deals.

The trap-rocks were carefully studied and described by Thomas Weaver in 1819.[1] He regarded it as

'evident that the trap constitutes discontinuous beds included in and parallel to the continuous series of the stratified transition-beds';[2]

but, as a faithful disciple of Werner, he hastened to add that, since these stratified beds were

'undeniably aqueous products, I do not perceive how we can avoid extending the same origin to trap also when found under similar circumstances.'

---

[1] Trans. Geol. Soc. ser. 2, vol. i, pt. ii, p. 317 [2] *Ibid.* p. 335.

In the same part of the Transactions (p. 216) appeared Buckland & Conybeare's classical 'Observations on the South-western Coal District of England.' They stated that it had been their intention to devote a chapter to the district immediately north of Tortworth; but owing to the presentation of Thomas Weaver's detailed paper, they determined to suppress their own more rapid sketch. They entered a protest, however, against Weaver's general conclusions.

'Two masses of amygdaloidal trap,' said they, 'are found traversing the transition-limestone and the Old Red Sandstone, which from their general parallelism to one another and to the strata which bound them, might appear at first sight to be regular beds. We are of opinion, however, after a careful examination of their course, that they really are portions of dykes irregularly traversing the other rocks. The thinness of these masses at their eastern extremity contrasted with their thickness on the west towards Woodford Green, and more especially the mode in which at the latter place they penetrate among and entangle fragments of the contiguous coralliferous limestone, which have been altered by the contact; these are the circumstances which have induced us to form this opinion concerning their nature.' (Trans. Geol. Soc. ser. 2, vol. i, pt. ii, 1819, p. 248.)

The statement here made, that the trap traverses the transition-limestone and the Old Red Sandstone is erroneous. Whatever be its mode of origin, the trap is certainly confined to the Silurian. At Damery Bridge, however, it overlies a red shale with abundant mica-flakes. It is possible that this was mistaken by Buckland & Conybeare for Old Red Sandstone. But the occurrence of *Lingula Symondsi*, Salt. in these shales places their Llandovery age beyond question.

In his 'Silurian System' (1839), Murchison strongly advocated the intrusive origin of the igneous rocks. On pp. 457–58 he remarked that

'The Tortworth trap-rocks whether viewed upon the natural surface, or in any of the numerous quarries in which they have been laid open, consist almost exclusively of amorphous masses, of irregular shape and unequal thickness, which protrude through and dislocate the overlying strata; sometimes throwing them off in discordant directions, at other times enveloping their fractured and dismembered portions within the masses of the trap.'

A description of the igneous rocks of the Tortworth district is included in Phillips's Geological Survey Memoir (vol. ii, pt. i, 1848) on 'The Malvern Hills compared with the Palæozoic Districts of Abberley, etc.' On p. 194 he says:—

'The manner in which the trap ... appears among the strata is of that kind denoting irruption and partial interposition. About Charfield Green, and in the line from Avening Green, through the wood, the trap shows for certain distances a parallelism to the stratifications and a lamination of its own substance corresponding thereto, but this is continually interrupted by that irregularity of admixture, inter-ramification, and including of stratified masses which always belong to irruption-trap. Successive flows of the pyrogenous rock on different levels of the Caradoc [Llandovery] deposit, with limited local disturbances, seem to be clearly indicated by all the facts observable. The trap appears only in the midst of Caradoc [Llandovery] beds, it is partially interstratified with them, follows their inclinations, and yet is partially injected amongst them; it is, therefore, an irruptive trap, but of what particular geological age we have some probable indications rather than complete and certain proof.'

These indications, he thought, point to the fact that

'the Tortworth traps are of the Caradoc [Llandovery] period,' and 'are, in fact, contemporaneously effused traps, most probably the fruit of limited and repeated pressures on the interior liquid masses of the earth, followed by solidification at small depths below, or even in part at the surface of the sea-bed.' [1]

Reference is made to the igneous rocks of the Charfield district in the first of a series of papers on the Geology of the Bristol Coalfield, read before the Bristol Naturalists' Society by Mr. W. W. Stoddart in 1873. Rough sections are given which show an intrusive boss of greenstone. They are admittedly diagrammatic and not drawn to scale, and they are unquestionably misleading. Thus the altered Llandovery Beds are described as 'vesicular and amygdaloidal'!

In Mr. H. B. Woodward's Geological Survey Memoir on 'The Geology of East Somerset & the Bristol Coalfields' (1876), the trap-rocks are briefly noticed, and Phillips's description of their nature summarized.

Sir Archibald Geikie devotes a short section to the 'Upper Silurian (?) Volcanoes of Gloucestershire' in his work on the 'Ancient Volcanoes of Great Britain' vol. i (1897) p. 238. He summarizes the views of Weaver, Murchison, and Phillips, and adds the following sentence:—

'If, as seems probable, some of them [the trap-rocks] are really interstratified, they form the youngest group of Silurian volcanic rocks in England, Scotland, or Wales.'

One of the excursions in connection with the Bristol Meeting of the British Association (1898) was to Tortworth, and one of us wrote in the excursion-guide (p. 9) as follows:—

[The traps] 'undoubtedly constitute somewhat irregular masses, but their limitation to the Upper Llandovery Beds, their general parallelism to the strike of the strata, their often exceedingly vesicular structure, and the occurrence of red ashy-looking beds in their neighbourhood, seem to lend support to the view adopted by Phillips that they are of Upper Llandovery age, and not subsequently injected as dykes.'

It is thus seen that the leading authorities who have studied the district reach somewhat divergent conclusions. According to Weaver, the traps are interstratified with the sedimentary series; Buckland & Conybeare, followed independently by Murchison, regarded them as intrusive dykes injected subsequently to the deposition of the Silurian strata; while Phillips assigned them to an age contemporaneous with the beds in which they are included, and described them as partly interstratified as lava-flows, and partly injected among the sedimentary deposits. In Buckland & Conybeare's map two bands of trap, roughly parallel, are marked. Weaver draws seven or eight parallel bands in Michaelswood Chase (= Mickle Wood); William Sanders and the officers of the Geological Survey draw three or four bands.

[1] Mem. Geol. Surv. vol. ii, pt. i (1848) p. 195.

II. Description of the Exposures.

An examination of the map (see Pl. X) shows that the igneous rocks occur, broadly speaking, on two horizons—a lower to the east and north-east, and an upper to the west and south-west. Both trap-horizons are represented at Charfield Green. Farther north the Silurian strata are overlain unconformably by Keuper Marls. Beyond this the trap of the lower horizon courses from Damery Bridge through Mickle Wood to Woodford Green, and then curves round along the northern rim of the basin to Middle Mill, beyond which it cannot be traced. The trap of the upper horizon appears at Avening Green, and probably courses through Crockley's Farm (where it was proved by the Earl of Ducie) to Daniel's Wood. According to the Surveyors' mapping, a fault marks its north-eastern boundary. We now propose to deal with these exposures in detail.

(*a*) The Charfield-Green Exposures.

The two bands of trap are here seen, one on each side of the Midland Railway, Charfield Station being situate near the middle of their course. Their direction is nearly north-north-west and south-south-east, approximately parallel to the railway-line. At both ends they are overlapped by Keuper.

(1) The easterly or lower band.—The only definite exposures of this band that we have been able to detect are seen in the bed of the little stream which, crossing the railway between the village and Hillhouse Farm, meets the Little Avon west of Elbury Hill. But in the Geological Survey Map a more extensive band is shown.

Between the line and a little cottage on the bank of the stream are fairly good exposures of an unfossiliferous red sandstone, probably of Llandovery age, with a dip to west 20° south, decreasing as one proceeds eastward from 37° to 15°. Behind the cottage, in the corner of the field, is a good exposure of the trap, a fairly-fresh, compact, non-amygdaloidal rock. In the stream near by, the trap is also clearly seen, and is here markedly amygdaloidal, some of the original vesicular cavities being filled with a black specular-looking chloritic mineral. The contact of the trap with sedimentary beds is unfortunately obscured, and no sedimentaries are seen in the stream-bed beyond and below the trap. But 150 yards farther north, by the hedge in the next field, we obtained Llandovery fossils, though not actually *in situ*.

The characteristically amygdaloidal nature of the trap in the stream-bed suggests that it is a contemporaneous lava, but these exposures show little upon which definite conclusions can be based.

(2) The westerly or upper band.—There is a good exposure of the trap in an old quarry (Cullimore's) lying close to the railway-line north-east of Poolfield Farm.[1] It is here in parts compact, in

[1] A section in this quarry is figured by Murchison, in the 'Silurian System' 1839, p. 459, which shows bands of indurated shale and thin curved masses of shelly sandstone and of gritty impure limestone included within the mass of the trap. No such inclusions are now visible.

parts amygdaloidal, but much weathered and containing a large amount of secondary calcite.

At one point in the western part of the quarry is a small but instructive exposure, giving the following section. At the top:—

	Inches.
Red marly shale	4
Band of grey sandstone	$\frac{3}{4}$ to $1\frac{1}{2}$
Red marly shale	8
Calcareous ash, with lapilli and fossils	9
Highly amygdaloidal trap, with an exceedingly irregular surface	12 (seen).

The calcareous ash is a well-marked rock, showing in a hand-specimen many fossils, shaly patches, small geodal cavities lined with quartz, and a fair number of characteristic lapilli, the largest being 2 inches long. In a microscopic section it is seen to be a very definite ash, with the following constituents:—

(*a*) Small lapilli showing good felspars, and generally much iron-stained.
(*b*) Felspar-crystals of fair size, some of which still exhibit twinning.
(*c*) Quartz-grains.
(*d*) Small shaly patches.
(*e*) Fossils.

These are all cemented together by calcareous matter, and calcite occurs plentifully in veins and patches, some of which are well cleaved.

Mr. F. R. Cowper Reed, M.A., F.G.S., to whom we wish to express our heartiest thanks for the very great amount of trouble that he has taken in the examination of our fossils, has identified the following forms from the ash-band:—

Atrypa reticularis, Linn.
Spirifera plicatella, var. *globosa*, Salt.
Rhynchospira Baylyi, Dav.
Leptæna rhomboidalis, Wilck.
Orthis calligramma, Dalm.
O. polygramma (?) Sow.
Cyrtoceras sp.

He regards this assemblage of fossils as probably indicative of Wenlock age. In this connection it is interesting to recall that one of us has noted[1] the occurrence of Wenlock Beds in a field south-west of Poolfield Farm. The shale at this spot is crowded with *Cœnites juniperinus*, Eichw., and overlain by a band of limestone. This spot is about 350 yards from Cullimore's Quarry.

Whether the fossils of the ash-band are of Wenlock age, or occur near the top of the Upper Llandovery Series, there seems little doubt that their association with well-marked lapilli, with felspars, and with other ashy material, affords the strongest possible evidence that there was contemporaneous volcanic activity in Silurian times, and renders it extremely probable that the trap is a contemporaneous lava. With this conclusion the very uneven surface and the highly amygdaloidal character of the trap itself are in agreement.

The trap is seen again, on about the same horizon, farther south-east, in the garden of a cottage on the south side of the Bibstone road opposite Warner's Court. It is here much shattered, very

[1] Brit. Assoc. Excursion-Guide to Tortworth, 1898, p. 11.

vesicular, and contains quartz-grains. Its relation to the sedimentary beds is not here seen.

We have not been able to find any trap *in situ* farther south; but fragments of trap occur in cottage-gardens. Unfossiliferous sandstone, resembling those of the Llandovery Series, is found in Fowler's Court Farm-yard, near the railway, south of Charfield-Green Station. If, as is probable, the trap-band pursues the course indicated in the Geological Survey Map, this sandstone lies a score or two of feet beneath it.

(*b*) The Avening-Green and Daniel's Wood Exposures.

These probably mark the course of the upper Charfield-Green band, or of a distinct band at about the same horizon. But between Charfield Green and Avening Green the Silurian strata are overlain by Keuper.

Immediately west of the little hamlet of Avening Green is a large, shallow, long-disused quarry showing good exposures of the trap. The rock, which is much weathered and shattered, is somewhat amygdaloidal. In the quarry, scattered over the fields to the north, and built into the adjoining walls, are numerous blocks of a calcareous sandstone of Llandovery facies, containing *Cœlospira hemisphærica*, Sow., *Rhynchonella nucula*, Sow., *Rh. llandoveriana (?)* Dav., *Atrypa reticularis*, Linn., and *Chonetes striatella*, Dalm.; but there is no visible point of contact between the trap and the sedimentaries *in situ*.

On the left bank of the stream, due north of the cottages, Llandovery Beds underlying the trap are seen *in situ*. The following fossils have been determined by Mr. F. R. Cowper Reed:—

Encrinurus punctatus, Brünn.	*Chonetes* sp.
Calymene sp.	*Stropheodonta* sp.
Phacops sp.	*Lindstrœmia subduplicata*, M'Coy.
Tentaculites sp.	Crinoid-remains.
Cyclonema coralli, Sow.	

In William Sanders's map, and that of the Geological Survey, the Avening-Green exposure of trap is prolonged as a narrow band stretching west-north-westward past Crockley's Farm to unite with the Daniel's Wood exposures. Near Crockley's Farm, it has been proved by an excavation, from which Lord Ducie obtained large bun-like geodes; but we have not been able to find any indications of its course at intermediate points, nor is the ground favourable for tracing it in any detail. We find it difficult to realize on what data Murchison based his somewhat minute description[1] of its irregular course and marked variation in thickness. The officers of the Geological Survey drew a line of fault along the north-eastern margin of the trap-band; but on what field-evidence this was based we are unable to say.

When we reach Daniel's Wood, however, the evidences of the

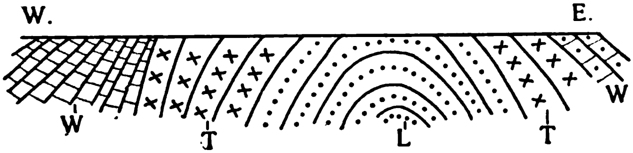
[1] 'Silurian System' 1839, p. 460.

trap are clear and abundant. Along the north side of the field, which is bordered on the east, west, and south by parts of this wood, runs a deepening trench or generally dry watercourse. Here are several exposures of amygdaloidal, much-weathered trap, containing in one place a block of baked shale. Good exposures of a fresher, more compact rock are seen at the southern end of the field near the border of the wood. And along the wooded slopes on the western side of the field, blocks of sedimentary rock and fragments of trap are strewn over the surface.

A little farther west, in the next field, is an exposure of pink, sandy limestone, dipping east-south-eastward at 25°. It was found to contain *Favosites cristatus*, Blum, *F. Forbesi*, M.-Edw., *Lindstrœmia* sp., and *Orthis* sp.

There are a number of exposures in the bed of the little stream which runs through the southern part of Daniel's Wood, and then flows between two fields before it joins the larger stream passing by Oldbrook Farm towards Middle Mill. Immediately west of the wood, between the boundary-hedge and a small footbridge, beds of limestone and sandstone occur dipping 30° north-westward; but a little higher up the stream, within the limits of the wood, the dip increases rapidly until it reaches 75°—the direction remaining north-west. About 60 paces from the hedge, trap is found crossing the bed of the stream, and apparently striking parallel to the sedimentary beds which here overlie it. Unfortunately, the exact boundary between the igneous rock and the sedimentary beds is not exposed.

Fig. 1.—*Section across the southern end of Daniel's Wood.*



Scale: 12 inches = 1 mile.

W = Wenlock Limestone (that at the eastern end of the exposure is sandy).
T = Trap.
L = Upper Llandovery Sandstone.

According to the Geological Survey mapping, the stream here traverses beds of Ludlow age. The fossils which we collected from the limestone-bands overlying the trap indicate, however, that the strata are Wenlock. The following were identified by Mr. Reed:—

Calymene Blumenbachi, Brongn.
Beyrichia Klædeni, M'Coy.
**Strophonella funiculata*, M'Coy.
Str. euglypha, His.
Leptæna rhomboidalis, Wilck.
**Plectambonites (?) Fletcheri*, Dav.
Orthis biloba, Linn.
Rhynchonella (*Camarotœchia*) *diodonta*, Dalm.
Atrypa reticularis, Linn.
Pentamerus sp.
**Periechocrinus moniliformis*, Mill.

* Indicates most abundant species.

In the bed of the stream, both here and higher up, are weathered fragments of a band which we have not found *in situ*, but which from the mode of occurrence of the fragments must come from a horizon below the trap. The following suite of fossils, identified by Mr. Reed, indicates Upper Llandovery age:—

Phacops Weaveri, Salt.
Cheirurus bimucronatus, Murch.
Encrinurus punctatus, Brünn.
Calymene Blumenbachi, Brongn.
Lichas sp. (hypostome).
Cornulites serpularius, Schloth.
Horiostoma globosum (= *sculptum*, Sow.).
Pleurotomaria sp.
Orthonota sp.
Atrypa reticularis, Linn.
Spirifer crispus, His.
Sp. elevatus (?) Dalm.
Stropheodonta compressa, Sow.
Leptæna rhomboidalis, Wilck.
Pentamerus sp.
Orthis sp.
O. elegantula, Dalm.
Rhynchonella (*Wilsonia*) *Wilsoni (?)* Sow.
Meristella angustifrons, M'Coy.
Favosites gothlandica, Fougt.
F. Forbesi, M.-Edw.
F. sp.
Cœlospira hemisphærica, Sow.
Aulopora serpens, Linn.
Lindstræmia bina, Lonsd.
L. subduplicata, M'Coy.
Crinoid-remains.

We have said that 60 paces within the wood the trap occurs, underlying the Wenlock limestones and sandstones. All the exposures for a considerable distance along the bed of the streamlet show igneous rock, which also crops out in the slopes to the north of it, and is continuous with that already spoken of as running along the western border of the field (shown on the 6-inch Ordnance Map) as almost encircled by parts of the wood. Unfortunately, as the stream is traced up farther east, there is but scanty and inconclusive evidence of the nature and disposition of the strata. After a gap, in which the banks at present show only recent stream-wash, the trap is again exposed for a short distance; and yet farther east, just within the wood on its eastern side, sandy beds occur dipping 55° south 15° east, that is to say, in a direction nearly opposite to that which is found on the other side of the trap-exposures near the western border of the wood. Without further evidence than is at present obtainable it is difficult to interpret the disposition of the strata. There may be faulting; but, on the whole, we are inclined to believe that here is a local anticline on each side of which the Wenlock Beds occur, the underlying arch of trap being so denuded as to bring in Upper Llandovery Beds, not seen *in situ*, though they afford the weathered fragments obtained from the bed of the stream. These occur only in that part of the stream-bed which lies below the point where we conjecture the crown of the denuded anticlinal arch to lie. None were found higher up the stream, farther east.

The occurrence of such an anticline (see fig. 1, p. 273) would serve to explain the broadening out of the trap at the surface, in the hog's-back of the field of which we have spoken as surrounded by parts of Daniel's Wood.

(*c*) The Damery, Mickle-Wood, and Middle-Mill Exposures.

These exposures seem to lie on the lower of the two main trappean horizons.

There are two small isolated occurrences of trap in the fields east and west of Whitehall Villa, which lies a short distance along the road leading from Damery to Charfield Mills. They show a compact, non-amygdaloidal, but much weathered rock. Their relation to the sedimentary beds is nowhere seen, and their connection with the general trend of the exposures a little farther west cannot be ascertained.

In some respects the most important exposure of igneous rock in this district is that of the large quarry at Damery Bridge. The main part of this quarry is excavated in a compact, reddish, tough rock which is used for road-metal. In parts, and especially near the base and top of the inclined band, the rock is highly amygdaloidal, and in many places contains numerous fragments of baked shale. The amygdules are of calcite or chlorite, or both. Where these contents have weathered out, for example in fragments which have long been exposed on the surface, the structure is exceedingly vesicular.

At the top south-western corner of the quarry fairly compact trap is seen, resting on red micaceous shales in which *Lingula Symondsi* has been found in considerable numbers. The shale dips at 35° south 20° east, and between it and the more compact rock is a weathered, shattered, and more vesicular bed. In the extreme western part of this exposure a fault, with a throw of a few feet, is seen bringing the shale against the igneous rock. The general trend of the trap-band in the quarry is approximately parallel to the strike of the red shales.

The relation of the sedimentary beds to the upper surface of the trap is not seen in the quarry. Sandstone, however, occurs in the banks of the stream near Damery Bridge, and farther south, on the other side of the stream, is a small excavation beneath a cottage to the east of the road. The section here exposed shows the following beds, dipping 30° southward:—

	Inches.
Sandy limestone, highly fossiliferous	4
Shaly parting	½
Sandstone, becoming calcareous and highly fossiliferous below, the fossils being mainly converted into peroxide of iron	24
Shaly parting	3
False-bedded flaggy strata	5
Shaly parting	3
Sandstone	2
Shale	2
Hard sandstone, with two highly fossiliferous calcareous bands	24
Shale	6
Sandstone	4
Shale	1½
Sandstone down to the base of the exposure.	

The fossils from this quarry, as identified by Mr. Reed, are:—

Cœlospira hemispherica, Sow.	*Stropheodonta compressa*, Sow.
Rhynchonella nucula, Sow.	*Phacops Weaveri*, Salt.
Orthis elegantula (?) Dalm.	*Cheirurus* sp.
Atrypa reticularis, Linn.	*Favosites Forbesi*, M.-Edw.
Chonetes striatella, Dalm.	Crinoid-remains.

Farther up the road leading southward from Damery Bridge, about 125 feet of Upper Llandovery Beds, consisting of grey shales and sandstones, with occasional fossiliferous calcareous bands, are seen in the banks. These lie between the upper and lower trap-horizons, and contain the following assemblage of fossils:—

Phacops Weaveri (?) Salt.	*Pentamerus undatus (?)* Sow.
Ph. Downingiæ (?) Murch.	*Cœlospira hemisphærica*, Sow.
Encrinurus punctatus, Brünn.	*Atrypa* sp.
Calymene Blumenbachi, Brongn.	*Plectambonites* sp.
Orthis hybrida (?) Sow.	*Meristella* sp.
O. calligramma, Dalm.	*Lindstrœmia uniserialis*, M'Coy.
Stricklandinia lens, Sow.	*Cornulites serpularius*, Schloth.
Str. lirata, Sow.	Crinoid-remains.

From Damery Quarry the trap-band may be traced in a slightly sinuous line through Mickle Wood. It has been worked in a series of long-disused and thickly-overgrown quarries. The trap is generally much weathered and shattered, vesicular fragments being found on the quarry-floor. But to the north, near two small ponds (south-west of the 'M' of Mickle Wood, on the 6-inch Ordnance Map), the trap is more compact, and in its microscopical characters is identical with the Damery rock. On the western side of the quarries here the sedimentary beds may be found by removing the surface-soil. Their strike is parallel with the trend of the trap-band; but we have not succeeded in obtaining a junction-section showing the exact relations of the sedimentary beds to the trap.

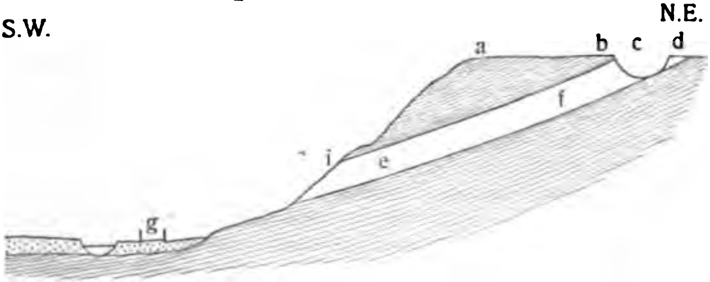
In Sanders's map and that of the Geological Survey two main bands are represented as crossing through Mickle Wood. We have been unable, after careful search, to find any evidence of the more easterly band. In several places recent trenches have been cut, for drainage purposes, just where the band is marked. But they show light-coloured, unfossiliferous, shaly material, the beds *in situ* not being reached in the trenches.

Apart from the main course of the trap through the wood, the only other indications of igneous rock that we have detected are on the steep slopes above the road, where it closely adjoins the stream near the old disused iron-mill. Here the ground is strewn with blocks of trap. If, however, the trap has the same dip as the sedimentary series, the slope of the surface is such that the igneous rock would reappear, as indicated in fig. 2, on the opposite page.

A little farther north-west than the line of this sketch-section a band of limestone crosses the road, at a point due north of Crockley's

Farm. From this we obtained *Cœlospira hemisphærica*, Sow.; *Chonetes striatella*, Dalm.; *Rhynchonella nucula*, Sow.; and *Phacops Weaveri*, Salt. Mr. Reed comments upon the presence of the rare and apparently local trilobite *Phacops Weaveri*, here and near Damery. This form seems, so far, to have been recorded only from this district.

Fig. 2.—*Sketch-section illustrative of the reappearance of the trap-band in Mickle Wood.*



a b d = Plateau of Mickle Wood.
c = Old quarry in trap.
e f = Trap-band with Upper Llandovery Beds above and below.
g = Road by stream (Little Avon).
i = Slope of valley where trap-blocks are abundant.

Between the point where the trap-band emerges from Mickle Wood and the pond at the cross-roads east of Woodford Farm, there are only uncertain indications of the course of the igneous rocks. Here, however, the trap is well exposed all round the pond, along the road towards Damery, and along that towards Woodford Farm. The rock is strongly amygdaloidal, and shows on the Damery road weathered bands with numerous minute pieces of shale. Close to the pond, on its north-eastern side, are two lenticular masses of baked shale, one about 10 feet long, caught up in the trap. This is the most intrusive-looking portion of the trap that we have seen; and, close by, the sedimentary beds seem to be striking towards the trap. Unquestionably the igneous rock here occupies a larger area than anywhere else in the district. This broadening of the trap is probably due here, as at Daniel's Wood, to the occurrence of an anticline. In any case the course of the trap curves round at this point, which forms the northerly limit of the synclinal basin, and the rock is again well exposed in a disused quarry near Middle Mill to the south-west.

This quarry is well worthy of a visit from those who are interested in igneous rocks, and is in many respects more instructive than the better-known exposure at Damery. There is a thick mass of amygdaloidal trap coursing into the hill towards the pond before mentioned. The upper and lower parts are comparatively compact, and have been extensively quarried. The middle portion, which has been left outstanding by the quarrymen owing to its irregular character and

comparative worthlessness for road-metalling, is much shattered and disturbed, shows plentiful veining and many slickensided faces, and is in places full of small fragments, about $\frac{1}{2}$-inch or less in diameter, of baked shale, so that at times it takes on an appearance not very dissimilar to a fragmental deposit. The most compact and freshest-looking rock in this quarry is in the south-western portion, where it contains plainly visible grains of clear quartz.

Along the north-western edge of the quarry are several exposures of sedimentary beds overlying the trap and lying on a roll of its irregular surface. These were noted by Weaver,[1] in whose time they were probably fresher and less overgrown than they now are. By removal of the soil, however, sufficient can even now be seen to throw light on the nature and origin of the rocks. In the most easterly exposure there lies upon the trap about 4 feet of sandy and ashy limestone dipping north-westward at 45° to 50°. Fossils are distributed throughout, and undoubted lapilli are plentiful in the top band and in the bottom 6 inches. These are well seen both in hand-specimens and in microscopic sections, and indicate in the most unmistakable manner the occurrence of contemporaneous volcanic activity. This section alone shows that here on the lower trap-horizon, as at Charfield Green on the upper horizon, whatever be the nature of the trap itself, there are contemporaneous volcanic ashes. And their relation to the trap, together with its highly vesicular character, strongly suggests, if it does not prove, that the trap itself is a contemporaneous lava.

In the ashy limestone Mr. Reed identified the following fossils:—

Cheirurus sp.
Pleurotomaria sp.
Orthis calligramma, Dalm.
O. rustica, Sow.
O. polygramma, Sow.
Atrypa imbricata (?) Sow.
Stricklandinia lirata, Sow.
Leptæna rhomboidalis, Wilck.
Pentamerus undatus (?) Sow.
Favosites gothlandica, Fougt.
F. Forbesi, M.-Edw.
F. Bowerbanki (?) M.-Edw. & Haime.
Lindstræmia bina, Lonsd.

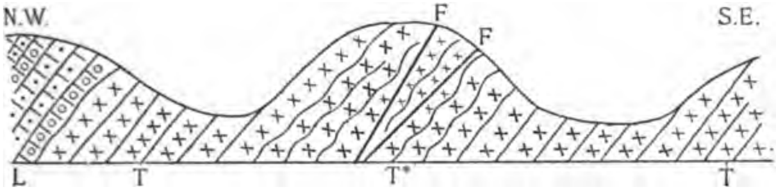
This assemblage of fossils shows that the beds are of Upper Llandovery age. There is a well-marked coral-band resting immediately upon the trap.

The only other trap-exposure lies farther south-west on the same line of strike, under the hedge on the left bank of the stream which joins the Little Avon at Middle Mill. The rocks here do not call for detailed notice. Above and below are more compact but somewhat vesicular bands, and between them, as in the old quarry, are more irregular and shattered bands, with abundant small amygdules, and containing minute fragments of baked shale, often very rotten and showing spheroidal weathering.

The trap-band is not traceable farther to the south-west, no exposures of rock *in situ* being visible.

[1] Trans. Geol. Soc. ser. 2, vol. i, pt. ii (1819) pp. 330–31.

Fig. 3.—*Section across Middle Mill (Horsley) Quarry.*



Scale: 1 inch = 30 yards.

L = Sandy limestone (Upper Llandovery) with lapilli. | T = Compact trap; T* = Crushed trap. FF = Faults.

III. The Petrology of the Igneous Rocks.

With regard to the nature of the igneous rock, Weaver describes it as a granular and compact greenstone, sometimes, though rarely, graduating into basalt, with occasionally disseminated portions of hornblende or augite, with granular and compact felspar, claystone, and amygdaloid. Buckland & Conybeare speak of it as 'amygdaloidal trap'; Stoddart, who gives analyses, one of which shows 10 per cent. of potassium oxide (!), as 'greenstone'; Phillips, as varying from an ordinary close-grained greenstone to largely vesicular amygdaloid. Mr. Rutley, in an appendix to Mr. H. B. Woodward's Geological Survey Memoir, gives a fuller and more careful description, based on the microscopic examination of sections. He notes the occurrence of olivine in a specimen from Charfield Green, and describes the rock as essentially a basalt. The rock from Damery he describes as a dark, brownish-grey, compact basalt, and notes the occurrence of plagioclase with twin-striation, of augite altered to a serpentinous material, and of magnetite. Mr. J. J. H. Teall's description of the Damery rock will be quoted under (c) (p. 281).

In our examination of these rocks we have been much helped by Mr. J. Parsons, B.Sc., who has determined the silica and alkali-percentages which we quote, and has supplied us with notes on certain points connected with the microscopical observation of some of the rocks. Our colleague, Mr. E. B. Ludlam, has kindly determined the specific gravities.

(a) The Charfield-Green Exposures.

(1) The easterly or lower band.—Behind the cottage by the stream, 300 yards south-east of Charfield-Green station, is an exposure of a reddish-brown, fairly fresh, non-amygdaloidal rock, which has a specific gravity of 2·74, and on analysis yielded the following percentages:—SiO_2 58·55; K_2O 1·81; Na_2O 2·98.

Mr. Parsons remarks on the extremely hydrous character of the

rock, and the silica-percentage, which, if raised to a moisture-free basis, would be 63·42. He remarks also upon the somewhat small alkali-percentage, and suggests that it may be accounted for by removal of alkali owing to hydrous decomposition. In section the rock is seen to be fairly coarse-grained, and to be mainly composed of altered felspar-laths, giving a maximum extinction-angle of 19°, which would indicate andesine of an acid type. Some of the felspars are larger than the others, but there are none which clearly belong to an earlier generation than the remainder. Minute colourless needles, giving an oblique extinction, and probably of felspar, can also be detected with a high-power lens. Small bastite-pseudomorphs after enstatite are plentiful, as are also grains of magnetite. Small irregular patches of a green chloritic mineral occur, and the whole section is stained with ferric oxide. The silica- and alkali-percentages, specific gravity, and microscopic characters, all show that this rock lies rather on the border-line between andesites and basalts. It may be called a basaltic enstatite-andesite.

The rock exposed on the right bank of the stream east of the cottage differs from that just described in several respects. In a hand-specimen it is seen to be browner in colour (less stained with ferric oxide), and to contain numerous dark amygdules, generally between 2 and 4 mm. in length. In section the felspar-laths are seen to be much smaller than in the rock just described, and minute needles, probably of felspar, can be detected with a high power. There are no phenocrysts of felspar. Small grains of magnetite and patches of a green serpentinous mineral, some of the latter being probably pseudomorphs after enstatite, are very plentiful and evenly distributed. The amygdules are generally formed of a pale-green, highly spherulitic chlorite, or sometimes partly of chlorite, partly of calcite. Round the amygdules the rock is stained with ferric oxide.

(2) The westerly or upper band is best exposed in the old quarry (Cullimore's) by the railway. It is a much-weathered rock, with abundant calcite occurring not only in large amygdules, but also in irregular patches uniformly disseminated. In section it is seen to contain comparatively little magnetite. It differs from many of the rocks of the district in containing a few large phenocrysts of felspar, which are very greatly altered and show corrosion.

The exposure of this band on the Bibstone road, opposite Warner's Court, is noteworthy for the fact that the rock here contains rounded grains of quartz. Similar grains are met with at several other localities in the district, and will be dealt with later (p. 282). This rock shows also well-marked phenocrysts of altered felspar, and an exceptionally large amount of magnetite. It may be termed a porphyritic basalt.

(b) The Avening-Green and Daniel's Wood Exposures.

The rocks exposed at Avening Green are so much weathered that we had no sections cut.

The trap exposed in the stream crossing Daniel's Wood is of a rather different type from most of the others. The felspars appear as—(i) minute needles; (ii) laths which are generally shorter and wider than is usually the case in these rocks, and give a maximum extinction-angle of 20°; and (iii) phenocrysts having a maximum extinction-angle of 44°. Small patches of brightly-polarizing enstatite occur which sometimes show crystal-outlines. Other patches of rhombic pyroxene are more or less converted into bastite-pseudomorphs. Augite is also present, both in the groundmass and as phenocrysts. Grains of corroded quartz are met with again here.

The rock exposed at the end of the field which is almost surrounded by Daniel's Wood, is compact and dark brown, and shows in a hand-specimen small felspar-phenocrysts, numerous grains of quartz, and a few amygdules, one of which, reaching a length of 1½ centimetres, was filled with chalcedony. Mr. Parsons finds that the silica-percentage is 58·16, and remarks on the fact that it is lower than in the rocks from Charfield Green and Middle Mill (see pp. 279 & 282), in spite of the abundance of quartz-grains.

In section the rock is seen to be extremely similar to that just described from the stream crossing Daniel's Wood. The minute needles and felspar-laths are identical in the two rocks; but the phenocrysts, which are much rounded, are larger and more numerous in the rock with which we are now concerned than in the Daniel's Wood rock. They are very much altered, and are bordered by a wide band of fresh secondary felspar. Enstatite and augite are both plentiful. The larger crystals of enstatite are converted into bastite-pseudomorphs, and sometimes wrap round the ends of the felspar-laths in an ophitic manner. The augite is the freshest met with in any of the rocks of the district. The included quartz-grains are of the same type as elsewhere in the district, and the chalcedony filling the vesicles is sometimes spherulitic, giving a black cross under crossed nicols.

(c) The Damery, Mickle-Wood, and Middle-Mill Exposures.

The rock from Damery Quarry is certainly the one to which most reference has been made by former observers. As described by Mr. Teall in the Brit. Assoc. Excursion-Guide to Tortworth, 1898, p. 11:—

'It is a fine-grained, purplish, massive rock traversed by thin veins of calcite. Some of the joint-surfaces are coated with chlorite. Under the microscope the rock is seen to be mainly composed of felspars showing lath-shaped sections. A fibrous bastite-like mineral (apparently representing enstatite), carbonates, chlorite, and iron-ores, are also present. The felspars appear to be in part oligoclase, but orthoclase may also be present. The state of preservation of the rock is not such as to admit of precise determination.'

Stoddart's analysis[1] also relates to this rock. He gives 57·52 as the silica-percentage of an example 'taken in as pure a state as possible from the centre of the quarry.' The most remarkable feature of his analysis is, however, as previously mentioned, the fact that he tabulates 10·34 as the percentage of potash, and only ·72 as that for soda. The enormous percentage of potash is scarcely explicable except as an error or misprint, though it should be noted that Mr. Teall refers to the possible presence of orthoclase.

Our sections show that the felspar-laths often tend to assume an approximately parallel arrangement. Although there are a few crystals that are somewhat larger than the others, the Damery rock resembles those from Charfield Green in not showing a generation of felspars of distinctly earlier date than the laths. These, which are as a rule simply twinned on the albite-type, give a maximum extinction-angle of 16°, but as a general rule the angle is much smaller than this. Small grains of bastite-pseudomorphs after enstatite are very plentiful and evenly distributed.

Sections show that the rock exposed by the little ponds in Mickle Wood is identical with that from Damery Quarry.

The rock exposed by the pond at the cross-roads east of Woodford Green is noteworthy for the very large amount of serpentine present. Some of the patches show crystal-outlines, and we believe that here again the original mineral was enstatite. The included quartz-grains, which occur in so many of the localities in the district, are well seen in this rock, and show marked corrosion by the groundmass.

Mr. Parsons has determined the silica-percentage of the fresh rock referred to as occurring in the south-western portion of Middle Mill Quarry; it is 63·5, or calculating the result to a moisture-free basis, 67·08. This percentage is notably higher than that of the Charfield-Green rock, but the fact is easily explained by the abundance of free quartz.[2] Some of these quartz-grains were isolated by Mr. Parsons, who says of them

'the clear glassy appearance, fracture with absence of cleavage, infusibility in the blowpipe-flame, and absence of coloration imparted to the Bunsen flame, confirm the opinion that they are quartz. Whenever they are met with all indications go to show that the grains are of foreign origin, and that consequently the rocks in which they occur are not to be regarded as dacites.'

In most respects this rock belongs to the same general type as the rest. The groundmass shows numerous small grains of altered pyroxene and felspar-laths, the majority of which give a maximum

[1] Proc. Bristol Nat. Soc. vol. i (1876) p. 123.

[2] [Since the sending in of our paper Mr. Alfred Harker has drawn our attention to the widespread character of the phenomenon of the inclusion of quartz-xenocrysts in basic igneous rocks, and to two papers of his (Geol. Mag. 1892, pp. 199–206 & 485–88) dealing with the subject. The view which he there advocates is that the quartz crystallized out, not in the basic rock in which it now occurs, but in a magma of acid composition which once overlay the basic. This explanation seems to fit the facts better than that which regards the quartz-grains as fragments mechanically caught up by the magma.]

extinction-angle of less than 10°, though a few give an angle of as much as 40°. There is also a fair number of greatly-altered phenocrysts, which are often zoned by a band of fresher material, and sometimes show marked corrosion by the groundmass. Iron-ores are not at all plentiful. Patches of a brown isotropic and apparently glassy matrix occupy spaces between the felspar-laths. This rock may be called a pyroxene-andesite or basalt.

The predominant type of rock at Middle Mill Quarry is characterized by the abundance of ferric oxide and magnetite, the latter occurring in large irregular patches, and being in all probability not an original constituent. Large amygdules are also very plentiful, and are sometimes filled with calcite, sometimes with a green, often spherulitic chloritic mineral; or, again, the central part of the amygdule may be calcite, and the marginal part a chloritic mineral.

The amygdaloidal rock retains the same general characters in the exposure by the stream south of Middle Mill, but the iron-ores are more uniformly distributed

(*d*) Summary with regard to the Igneous Rocks.

The following are the main characteristics of the trap-rocks:—

Felspar-crystals of three types can sometimes be detected, namely: (1) minute needles; (2) abundant laths, which generally appear to be oligoclase or andesine; and (3) phenocrysts, sometimes of labradorite. Many other rocks show only the laths.

All the rocks show the presence of bastitic or serpentinous pseudomorphs after pyroxene. Most of this is certainly after a rhombic pyroxene, probably enstatite, but fresh augite is sometimes present. We have found no trace of hornblende or of olivine.

Iron-ore, generally magnetite, is always present as an original constituent, but the amount varies considerably. Ferric oxide, and magnetite apparently of secondary origin, are often present, sometimes in considerable quantities. Grains of quartz with corrosion-borders are present in most cases, and constitute one of the most characteristic features of the rocks.

A small amount of a very fine-grained, or sometimes probably glassy matrix is generally to be detected; but the rocks, as a whole, are more coarsely crystalline than is usually the case with andesites. Much chlorite and calcite are commonly present, often forming amygdules.

The silica-percentages obtained (58·16, 58·55, and 63·5; or, when raised to a moisture-free basis, 61·44, 63·42, and 67·08) are rather those of andesites than basalts, while the specific gravities (2·74, 2·99) are rather those of basalts.

On the whole, it may be said that all the rocks belong to the group of pyroxene-andesites or basalts, some being best regarded as pyroxene-andesites, and some as basalts.

IV. Conclusions.

We believe that we have confirmed or established the following points with regard to the igneous rocks of the Tortworth inlier:—

1. That well-marked tuffs occur, and that the trap-rocks are, both by inference and by internal evidence, lava-flows of the nature of pyroxene-andesites or basalts.
2. That they occur on two horizons which follow the north-eastern and northern boundaries of the Bristol Coalfield.
3. That the lower one is overlain by beds of Upper Llandovery age, and the upper one by beds of Lower Wenlock age.

EXPLANATION OF PLATES X & XI.

Plate X.

Geological sketch-map of the igneous rocks and associated sedimentaries of the Tortworth inlier, on the scale of 3 miles to the inch.

Plate XI.

Microscope-sections of andesites and tuffs.

Fig. 1. Calcareous ash from Middle Mill, Tortworth district. ×18. This shows a rounded lava-fragment, embedded in a matrix chiefly composed of quartz-grains, but showing much carbonate of lime.

2. Pyroxene-andesite from north of Daniel's Wood, Tortworth district. ×33. This shows needles and laths of plagioclase, varying considerably in size; also part of a large, much-altered felspar-phenocryst, bordered by a zone of fresh secondary material. Also a crystal of fresh augite, and by it a bastite-pseudomorph after enstatite, enclosing the ends of some of the felspar-laths in an ophitic fashion.

3. Pyroxene-andesite or basalt with quartz-grains, from Daniel's Wood, Tortworth district. ×16. This shows two grains of quartz corroded by the groundmass, and surrounded by a thick border chiefly composed of pyroxene. The groundmass shows fresh needles and laths of plagioclase, the latter varying considerably in size, and numerous small grains of pyroxene.

4. Calcareous ash from Cullimore's Quarry, by the railway north of Charfield Station. ×14. This shows numerous angular fragments of trap of several types, with quartz-grains and crystals of altered felspar embedded in a calcareous matrix.

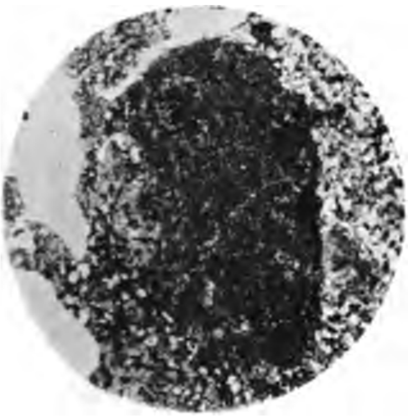
[No. 1 is from the lower band, and the other three are from the upper band.]

Discussion.

Prof. W. W. Watts pointed out the difficulty of establishing the contemporaneity of volcanic activity in any district, and particularly in association with Silurian rocks. The specimens of tuffs exhibited by the Authors appeared, however, to be genuine contemporaneous tuffs, and the Authors were to be congratulated on having established a new chapter of volcanic activity in Britain.

The Chairman (Mr. H. W. Monckton) and Gen. C. A. McMahon also spoke, and Mr. Reynolds briefly replied.

1.



X 18.

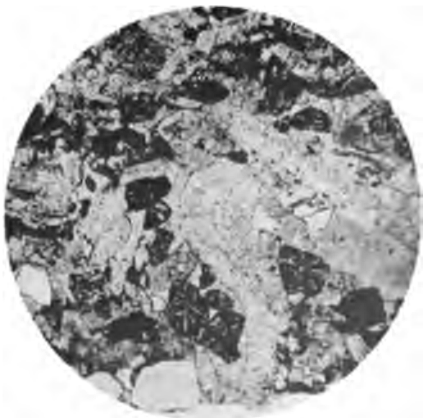
2.

X 33.

3.

X 16.

4.

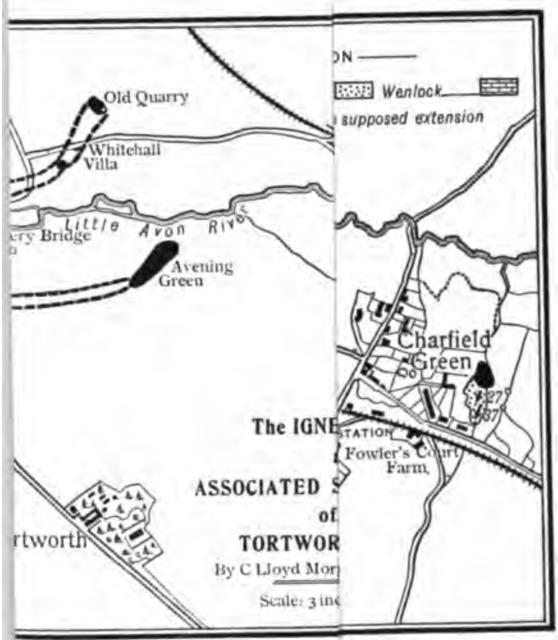


X 14.

Pyroxene-Andesites and Calcareous Tuffs from the Tortworth Inlier.

Reynolds and G. Brebner, photomicrogr. Bemrose

Vol. LVII, Pl. X.



ON
Wenlock
supposed extension
Old Quarry
Whitehall
Villa
Little Avon River
ery Bridge
Avening
Green
Charfield
Green
STATION
Fowler's Court
Farm
rtworth
The IGNE
ASSOCIATED S
of
TORTWOR
By C Lloyd Mor
Scale: 3 inc

19. *Note on a* WELL-SECTION *at* DALLINGHOO (SUFFOLK).[1] By the Rev. ROBERT ASHINGTON BULLEN, B.A., F.L.S., F.G.S. (Read April 24th, 1901.)

THE well here described was sunk in the garden of Dallinghoo Post-Office, near Wickham Market (Suffolk). Dallinghoo is about 4 miles north-west of Woodbridge, and about 161 feet above Ordnance datum. The well is one of three bored by a water-finder's advice. His counsels were successfully acted upon in two out of the three cases, and this result will probably help to keep the superstition alive in that district. In this Post-Office well water was found at a depth of 79 feet.

The section shows:—

	Feet.
Blue Chalky Boulder-Clay	53
Reddish sand and gravel	1
White sand and gravel.....................	16
Red sand and gravel	9

Below this the boring was not continued.

Mr. George R. Allen, of Wickham Market, the borer and builder of the well, has carefully collected the fossils from the Boulder-Clay, and has given me the boring measurements.

Besides *Gryphæa incurva* and *Ichthyosaurus* sp. (vertebra) the following fossils were found and were kindly identified for me by Mr. E. T. Newton, F.R.S.:—

Ammonites (*Ophioceras*) *raricostatus*, Zieten.
A. (*Cardioceras*) *excavatus*, J. de C. Sow.
A. (*Cosmoceras*) *Jason*, Reinecke.
Belemnites abbreviatus, Miller.
B. Owenii, Pratt.
B. sp.

In addition to these there is a concreted mass of indeterminable *Lima* and *Ostrea*, too young for identification, probably assignable to the Lower Lias. There are also large pieces of a dull-green bituminous shale, containing numerous fossils, showing young ammonites and brachiopoda (*Discina* sp.), and black shining objects, possibly fish-scales. This shale burns with a bright yellow flame, and gives off a disagreeable pitch-like odour.

A mass of quartz-grains, cemented by a dull-brown ferruginous material, is thought by Mr. Newton to be most probably Carstone.

The fragment of *Ammonites raricostatus* is very much worn at the upper (dorsal) surface and striated. *Belemnites abbreviatus* also is more than usually flat on one side, and shows longitudinal striæ.

[1] [This paper was read under the title 'Notes on Two Well-Sections'; but it was subsequently ascertained that a description of one of them, namely, that at Messrs. Jenner's Brewery at Southwark, had been drawn up by Mr. Whitaker for publication elsewhere, of which fact Mr. Bullen was not at the time cognizant.—ED.]

Some of the Boulder-Clay contains cretaceous matter in the form of 'race.' In places flat masses of fibrous gypsum were found, as well as tabular iron-pyrites. One fragment of selenite much resembles the selenite from the London Clay of Herne Bay and elsewhere.

The sands underlying the Boulder-Clay yielded no fossils of the Crag Series.

The stones from the Boulder-Clay were submitted to Prof. T. Rupert Jones, F.R.S., who reports as follows:—

No. 1 is a micaceous sandstone, possibly from the Coal-Measures of the Lower Carboniferous Series.

No. 2 is an argillaceous rock, micaceous and partly calcareous; laminated, a dense micaceous shale.

No. 3 is a quartzose sandstone with red cement, and with some white grains (felspar?); micaceous. This may possibly be Bunter Sandstone. The bluish coating of all is calcareous and argillaceous.

At my request Mr. Frederick Chapman, A.L.S., F.R.M.S., made a detailed microscopic examination of the sands, stones, and bituminous shale. The reason for examining the last-named was to ascertain whether the burning properties were due to the presence of ostracoda, as these entomostraca have been found very abundantly in the oil-shales of the Scottish Coal-Measures. His detailed report is as follows:—

(A.) Rock-Specimens from the Boulder-Clay at Dallinghoo.

[The numbers 1–3 correspond to the specimens described by Prof. T. Rupert Jones.]

1. An argillaceous gritty sandstone, with some mica; probably of Carboniferous age.
2. A laminated argillite, containing mica between the laminæ. Some obscure foraminifera and ostracoda are present in this rock. One of the foraminifera appears to be *Haplophragmium agglutinans*. Other organic remains are referable to echinodermata and mollusca, of either Carboniferous or Jurassic age.
3. A ferruginous and micaceous sandstone, with bedding-planes strongly marked. In thin section the quartz-grains are seen to be angular; some are in a state of strain, and show 'ripple'-structure under polarized light; moreover, granules of microclinic felspar and much muscovite-mica are present in the rock. This specimen resembles some fine-grained Triassic sandstones (Bunter Series).

(B.) Specimens from the Sand at Dallinghoo.

1. A Cretaceous chert with numerous sponge-spicules and foraminifera. Among the latter is a very perfect specimen of *Textularia trochus* seen in vertical section in the slide.
2. A pebble of flint, consisting almost entirely of a lithistid[1] sponge. In the hollows of the sponge are numerous outlines of foraminifera, seen in thin section. These foraminifera appear to be in nearly all instances *Globigerina cretacea*, of Cretaceous age.

[1] Dr. G. J. Hinde, F.R.S., concurs in this determination.

(C.) Bituminous Shale from the Well at Dallinghoo.

Its inflammable property is due to included fish- and cephalopod-remains.
The disintegrated shale yields numerous bones and scales of fishes. Some foraminifera, of the genus *Pulvinulina*, were also found.
No ostracoda were met with. [Both Mr. E. T. Newton and Mr. F. Chapman think that this shale is Kimmeridgian.]

(D.) Sand from the Well at Dallinghoo.

This consists largely of clear quartz-grains, subangular or well rounded in outline, and often showing highly-polished surfaces; a granule or two showed crystalline facets, which seems to point to an origin in the Triassic sandstones. There are also chips of iron-stained flints, and whitened fragments of the same, usually angular or subangular. A few rolled or chipped foraminifera are present, all undoubtedly of Cretaceous age, including *Textularia* sp., *Globigerina cretacea*, *Gl. marginata*, *Truncatulina lobatula* (with a chalky matrix adhering to it), and *Pulvinulina* sp.
The materials of the larger fragments consist of flint, chert (with sponge-spicules), quartz, and lignite.

In thus putting before the Geological Society the facts, so far as ascertained, from this interesting deposit, one is tempted to infer a somewhat north-westerly direction to have been the track of the ice which collected the material of the Boulder-Clay and subjacent sands.

My best thanks are due to Prof. T. Rupert Jones, Mr. E. T. Newton, and Mr. Frederick Chapman for their valuable help.

Discussion.

The Rev. Edwin Hill said he was pleased that attention should be directed to the materials of the Boulder-Clay. He agreed with the Author's view that, in Suffolk, these came chiefly from the west: his own belief was that little, if any, was from the north.

Mr. H. W. Monckton drew attention to a well in Southwark Bankside, No. 29, described by Mr. Whitaker, Mem. Geol. Surv. 'Geology of London' vol. ii (1889) p. 218, the section in which bears considerable resemblance to that described in the foregoing communication.

Prof. H. G. Seeley said that the thickness of the Thanet Sands in the Southwark well was very similar to the thickness of 40 feet found under the Bank of England; it was of interest, from the rapid thinning of the sand to the west and north-west.

The section at Dallinghoo appeared to show that the Boulder-Clay filled an ancient valley, like several in Cambridgeshire which are similarly filled with Boulder-Clay. The contents of the Boulder-Clay are almost entirely fossils of the Lias, Oxford Clay, and Kimmeridge Clay. It was remarkable that there were few, if any, recognizable examples of the rocks, by which those clays are commonly divided in the North of England, present in the Suffolk Boulder-Clay. He regarded the inflammable condition of the Kimmeridge Clay as always due to marine algæ.

Mr. A. E. Salter remarked that beds belonging to the Woolwich and Reading Series, etc., very similar to those found in the Southwark well-section, were exposed in the deep drain-cuttings between New Cross and Brockley, and also in the tunnel now being constructed between North and South Greenwich.

With regard to the Dallinghoo section he must congratulate the Author on his method of work. The absence of igneous rocks was noteworthy, while those regarded as of Bunter or Carboniferous origin were probably not derived directly from their parent rocks, but secondarily through the Lower Greensand, Cambridge Greensand, or even the Crag. All the specimens shown might very well have been derived entirely from the west.

Mr. E. A. Martin remarked that he understood that no specimens were preserved of the material brought up in boring the Southwark well. This was to be regretted, as the divisions between the Tertiaries were often very obscure. Such was frequently the case in other well-sections which he had examined, and if the material from each depth quoted in the engineer's tables were carefully preserved and labelled, much obscurity would be saved. This led the speaker to suggest a permanent resting-place for such material, in a museum or elsewhere, his experience being that, even in those cases in which the boring-engineers had gone to some trouble to retain carefully labelled specimens, these very soon became neglected, and labels became changed and specimens mixed, until they were worse than useless.

The Author said that, in his little paper, he had attempted to deal with the facts ascertainable rather than to theorize. The similarity, almost coincidence, of the well-section at Bankside, Southwark, mentioned by Mr. H. W. Monckton, with that of Messrs. Jenner was decidedly interesting, and pointed probably to the proximity of the two borings.

The thin stratum of acicular gypsum at Dallinghoo Well was so large in extent, so brittle in character, and occurred in so heterogeneous a deposit, that it could hardly have been originally deposited in its present state, but had most probably been formed since the deposition of the Chalky Boulder-Clay. Prof. Seeley's suggestion that the combustibility of the bituminous shale was due to the presence of algæ, while undoubtedly ingenious, was at variance with the ascertained facts; for, although cephalopod and other molluscan remains, as well as fish-bones and fish-scales, were abundantly present, no marine plants had been detected after the most minute microscopic investigation. In conclusion, he warmly thanked all the Fellows for the kind way in which they had received the first geological paper that he had read before the Society.

20. *On the* Skull *of a* Chiru-like Antelope *from the* Ossiferous Deposits *of* Hundes (Tibet). By Richard Lydekker, Esq. (Read May 22nd, 1901.)

Exactly twenty years ago I proposed[1] the provisional name of *Pantholops hundesiensis* for an extinct species of antelope, typified by an imperfect skull figured in J. F. Royle's 'Illustrations of the Botany, &c. of the Himalayan Mountains' 1839, pl. iii, fig. 1. I had only the figure to go by, as the paper was written in India, and the specimen was said to be in the Collection of the Geological Society of London. And till the other day, when my attention was called to it by Mr. C. D. Sherborn, I had never seen the specimen. Having, by the kind permission of the Council, obtained the loan of this skull, I am happy to say that my original determination is in the main confirmed by actual examination of the specimen. And since the fossil is of more than ordinary interest, and the original figure is highly unsatisfactory, I have thought it desirable to offer the present note to the Society.

The specimen was obtained by Messrs. Webb & Trail from Tibetan traders, by whom it was brought from the Hundes plain, on the far side of the Niti Pass; and it was presented to the Society by Capt. Webb.

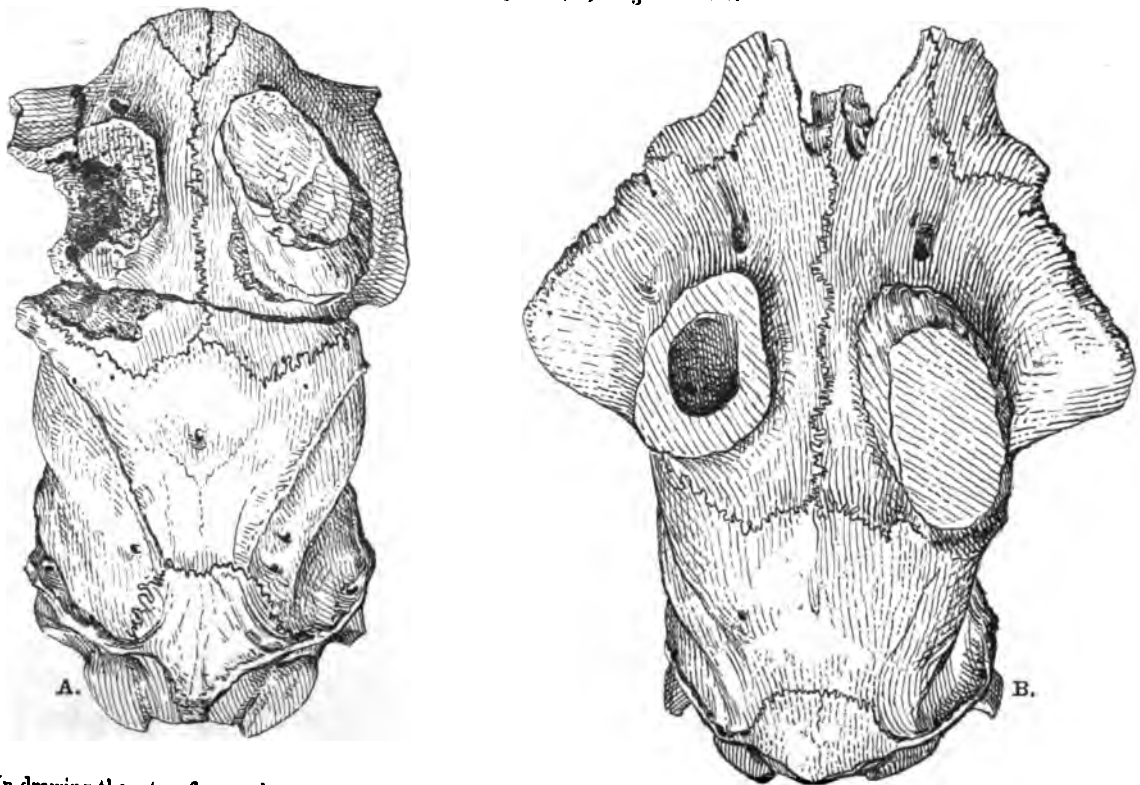
The skull in its present condition comprises the brain-case in a fairly perfect state, although lacking the edge of the frontal portion of the orbits. The right horn-core is broken off obliquely a short distance above the pedicle, while the second has been broken through the pedicle itself, showing the basal sinus. Mineralogically, the specimen is in much the same condition as Siwalik fossils from the Eastern sub-Himalaya.

I cannot find that the skull bears any resemblance to that of any genus of African antelope. As regards Indo-Tibetan forms, it is quite distinct from *Nemorhædus* and *Urotragus*, having an elliptical instead of nearly circular cross-section to the horn-cores; and it is equally distinct from *Gazella*, as is shown by the absence of large pits round the frontal foramina.

On the other hand, although of rather smaller dimensions, it comes very close to the skull of the existing chiru (*Pantholops Hodgsoni*) of Tibet in general characters. This is shown by the general form of the brain-case, and especially by the strong ridges marking the upper limits of the temporal fossæ, and the contour of the occipital surface. The frontal foramina are likewise simple perforations in the bone, without any expansion into pits. The upper portion of the nasals still remains, and shows that these bones occupied the same relative position as in the recent form, extending upwards in both as far as the lachrymo-frontal suture.

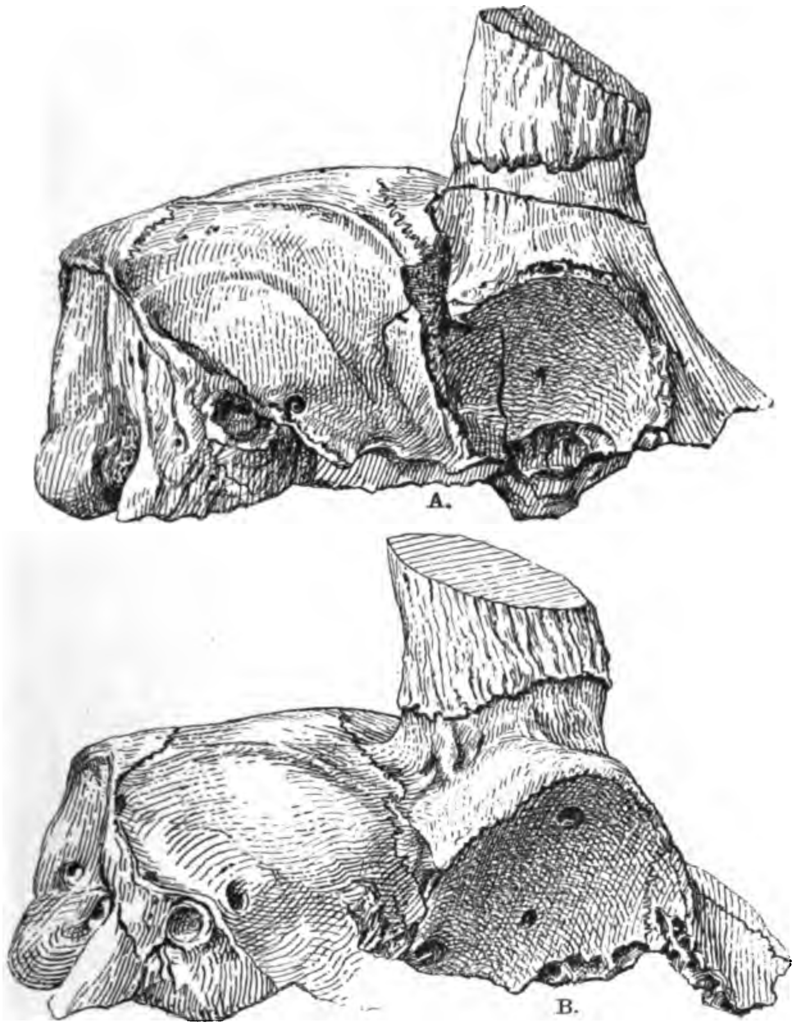
[1] Rec. Geol. Surv. India, vol. xiv (1881) p. 180.

Fig. 1.—*Upper aspect of the skull of* Pantholops hundesiensis *(A) and of the corresponding portion of the skull of a male* P. Hodgsoni *(B).* $\frac{2}{3}$ *nat. size.*



[In drawing these two figures the artist has, unfortunately, not placed the skulls in quite the same plane; the occiput of the fossil is more raised than in the recent specimen, thus showing more of the condyles.]

Fig. 2.—*Right lateral aspect of the same two specimens.*



The horn-cores have also the same highly elliptical cross-section, and the same general setting-on and upright direction: the long axis of the ellipse being set very obliquely to the middle line of the skull. In the fossil form the obliquity is indeed somewhat greater than in the modern chiru, and the horn-cores at starting appear to have been inclined a little forward instead of somewhat backward. (See fig. 2, p. 291.)

The result of this examination is thus to confirm my previous opinion that the fossil Hundes skull indicates an animal nearly related to the living chiru of the same region. And, for the present at least, I think that it may well be left in the same genus. The distinctive characters of the species, as compared with the chiru, will be, of course, its smaller size, the forward inclination of the basal portion of the horn-cores, and the greater obliquity of their setting-on.

In the paper already quoted I have given reasons for believing that this and other fossil mammal remains from the same region come from the horizontal deposits of Hundes, in which bones were found by Mr. C. L. Griesbach.[1] I also came to the conclusion that these beds were probably not older than the Upper Pliocene, and that they were deposited when the Hundes plain was approximately at its present elevation. A further inference was that the animals whose remains are found in these deposits must have lived after the elevation of the Hundes plain to its present height of some 15,000 feet above sea-level. Among these animals is a rhinoceros; and although it seems impossible that such a creature could now exist in Hundes, I have endeavoured to show that under somewhat altered climatic conditions it might have been an inhabitant of that desolate region.

As the affinity of the extinct Hundes antelope to the modern chiru of the same region seems to be now fairly well established (the original determination having been provisional), I see no reasons for departing in any respect from the position which I took up in 1881.

[1] Rec. Geol. Surv. India, vol. xiii (1880) p. 91.

21. *On some* Landslips *in* Boulder-Clay *near* Scarborough. By Horace Woollaston Monckton, Esq., F.L.S., V.P.G.S. (Read June 5th, 1901.)

In the valleys which have been cut through the tabular Howardian Hills, and on the hills themselves, there is a great scarcity of deposits of Drift, but along the Yorkshire coast we find a remarkable band of Boulder-Clay with an average width of about 2 miles. The consequence is, that whereas inland the solid rock (Corallian, Oxfordian, etc.) is exposed from the top of the hills to the bottom of the valleys, along the coast the old pre-Boulder-Clay surface of the ground is obscured, and only the higher points of solid rock, such, for instance, as Oliver's Mount, project through the Boulder-Clay covering.

The old surface-features of the ground have been to some extent exposed by the action of the sea. Thus the old Corallian-capped hill upon which Scarborough Castle stands has been worn out of the Boulder-Clay in process of denudation, and even now a capping of that clay remains on its top.

South of the castle there was in pre-Boulder-Clay times a deep valley; for the Drift has been penetrated to a depth of over 100 feet below sea-level,[1] and this valley has been to a certain extent re-excavated by the stream which flows from the Mere.

The south side of the valley was formed of sandstones belonging to the Estuarine Series, which at High Wheatcroft are covered by Cornbrash and Kellaway's Rock; but beyond White Nab we come to another old depression, which is cut through by the sea in Carnelian Bay. The depression sinks very little below high-water mark, but no doubt it may be the upper part of a valley running in a westerly direction to join the old River Derwent. Even now the stream rising so near the cliffs as Low Wheatcroft flows in a westerly direction to the Hertford River.

Carnelian Bay, which scarcely deserves the name of bay, comprises the coast between White Nab on the north and Osgodby Nab on the south. The Oolitic rocks (Scarborough Limestone and Estuarine Series) form the lower half of the cliff at White Nab, and the old pre-Drift surface slopes down towards the south, and a little north of Osgodby Nab it sinks below sea-level.

The present surface of the ground is, however, fairly uniform—being, indeed, a flat with a slight inland slope,—and consequently the Drift, a mere capping 6 feet thick at High Wheatcroft, thickens till it forms half the cliff at White Nab, and the whole of the cliff in the southern half of Carnelian Bay. From this flat a broken ridge runs out in the middle of the Bay, and a spur also projects towards Osgodby Nab.

[1] C. Fox-Strangways & G. Barrow 'Geology of the Country between Whitby & Scarborough' Mem. Geol. Surv. (1882) p. 51.

Fig. 1.—*Carnelian Bay, Scarborough.*

Fig. 2.—*Slipped Boulder-Clay in Filey Bay.*

[The surface of cliff represented measures about 15 × 24 feet.]

Fig. 1 is a reproduction of a photograph taken by myself on September 26th, 1896 (Brit. Assoc. Coll. of Photos. 2483). It was taken from the shore a little north of Osgodby Nab, the camera pointing in a direction a little west of north. The rock of Scarborough Castle forms a prominent object in the distance. On the right there is solid rock, a reef of sandstone below high-water mark; and on the left is a low cliff of Boulder-Clay, all of which has slipped down from a higher level.

When the clay is dry it has a tendency to crack vertically, and a sort of columnar structure is produced. The large pillar of clay seen in the view was, I believe, due to the action of the waves on clay with such vertical cracks.

I have for several years noted details of landslips in the Drift near Scarborough, and, as in other cases,[1] they may be classed as:

(1) Mud-flows.
(2) Earth-slips where the clay, though not actually mud, is at least partly in a plastic condition.
(3) Falls which, owing to the dryness of the clay, resemble rock-falls.

(1) I have only seen small mud-flows in Carnelian Bay; but some years ago I came upon one flowing across the footpath to Filey, near Yons Nab. It was of considerable size; in fact, I did not venture to cross it.

(2) Landslips of clay in a more or less plastic state are very common. I have already said that a columnar structure is set up in the dry clay, and after wet weather masses of this columnar clay slip forward, and the columns become curved and distorted.

During the slipping process a horizontal lamination is often produced in the moister part of the clay, and very pretty twisted structure may be observed which reminds one of gneissic banding. An example of 'augen'-structure in the Contorted Drift at Beeston, on the Norfolk coast, has been photographed by Mr. Strahan and described by Mr. Clement Reid.[2] A somewhat similar example is shown in fig. 2, reproduced from a photograph which I took on September 15th, 1900. It represents an area of about 360 square feet of the bottom of the cliff a little south of Filey. It will be noticed that the clay in this view, as well as in fig. 1, is full of boulders.

(3) When I was at Scarborough in May of the present year, I was told that a considerable landslip had occurred in Carnelian Bay. I believe that it happened on Whit Sunday, May 26th; I visited the Bay on the 28th, and found that the slip was in the nature of a rock-fall.

It originated from the spur of Drift which I have mentioned as running out from the Boulder-Clay flat towards Osgodby Nab. The Drift consists mainly of Boulder-Clay, but in places there is some

[1] Compare A. Baltzer's 'Ueber Bergstürze in den Alpen' Zürich, 1875 (reprinted from the Jahrbuch des Schweiz. Alpenclub, vol. x).
[2] Proc. Geol. Assoc. vol. xiii (1893) p. 66.

sand, and here and there a little gravel. There had been a long spell of dry weather, and the clay was hard and dry. Some rain fell on the Sunday, but whether it was in any way the cause of the slip I do not know. The slipped material appeared to be wholly Drift; the central part had travelled farthest, leaving a long deep depression behind it, and into this the sides had to some extent fallen.

On the solid clay at the sides of the slip were well-marked longitudinal striæ; in places I noticed a cross-striation on a small scale, and on a very few of the fallen blocks of clay striation could be seen. There was a certain amount of sand in the slipped material, but it consisted mainly of blocks of clay of all sizes and shapes: the largest blocks being at the back of the mass. The slipped mass projected on to the foreshore well below high-water mark, the front of the slip on the foreshore being about 200 yards from the ridge whence it started.

Discussion.

Mr. Hudleston said that he had no intention of offering any critical remarks on the Author's paper. The excellent illustrations shown on the screen called to mind many a well-known spot on the Scarborough coast, where the Jurassic rocks are in places so much obscured by Boulder-Clay. Without giving any opinion as to the cracks mentioned by the Author, he could not help noting a resemblance to glacier-ice in the behaviour of much of this Boulder-Clay, where crevasses and pinnacles of stony drift, weathering into fantastic shapes, remind one of similar features in Alpine regions.

The President also spoke, and the Author replied.

22. *On the* Passage *of a* Seam *of* Coal *into a* Seam *of* Dolomite.

By Aubrey Strahan, Esq., M.A., F.G.S.[1] (Read June 5th, 1901.)

[Plate XII.]

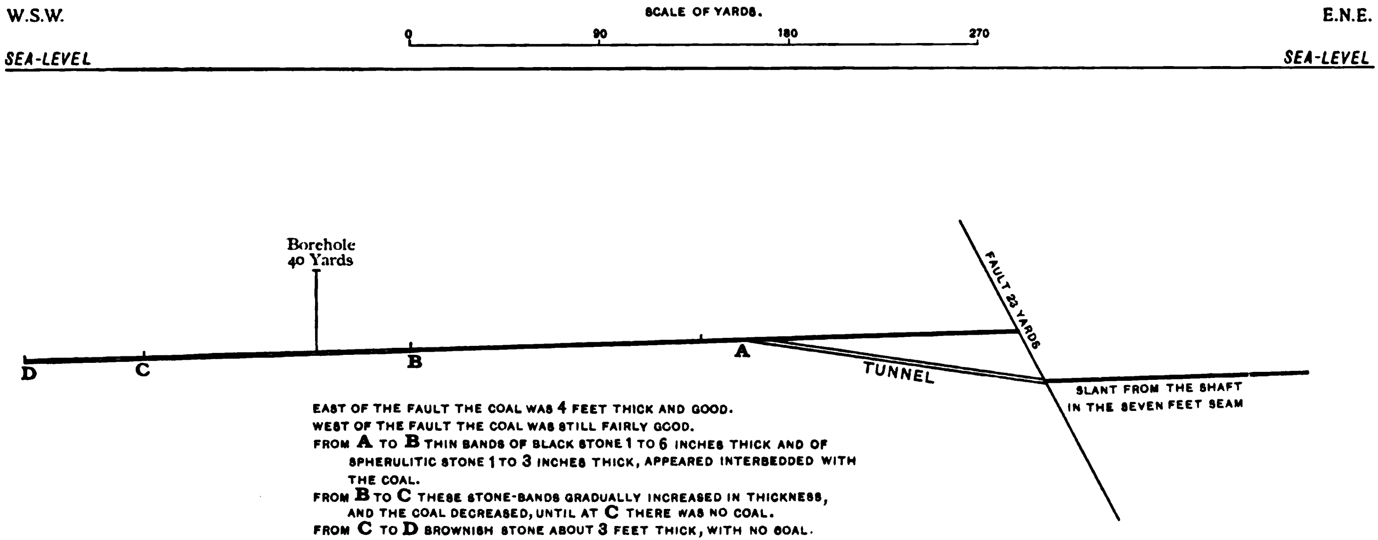
In the spring of the year 1900 I was informed by Mr. N. R. Griffith that the Seven-Feet Seam of the Wirral Colliery had been found to pass into stone of an unusual character. The matter seeming likely to be of scientific as well as of economic importance I received instructions from Sir Archibald Geikie, then Director-General of the Geological Survey, to visit the colliery and collect the facts. This I did in June, under the guidance of Mr. James Platt, the Manager, to whom I am indebted for the information concerning the working contained in the present paper.

Four workable coal-seams occur in this small Parkgate Coalfield, namely in descending order, the Six-Feet, Five-Feet, Seven-Feet, and Two-Feet. Though they cannot be precisely correlated with the seams either in Flintshire or South Lancashire, they almost certainly belong to the Middle Coal-Measures. The Seven-Feet Seam, with which alone we are now concerned, was reached at a depth of 148 yards in No. 1 Shaft, and the workings in it were carried westward under the estuary of the Dee for more than half a mile, as shewn in the accompanying plan (fig. 2, p. 299). For a distance of about 1600 yards from the shaft the coal was good and about 4 feet thick. A fault with an easterly downthrow of 23 yards was then encountered (fig. 1, p. 298), but the coal was regained by driving upward through the measures, and was found to be still fairly good. A few yards farther on, however, bands of stone from 1 to 10 inches thick made their appearance in it, some of them consisting, in Mr. Platt's words, of spherical pellets like gunshot. Gradually increasing in thickness at the expense of the intervening bands of coal, these stone-bands eventually constituted the whole seam, the last traces of workable coal disappearing at a distance of 250 yards from the point where the change first began. The slant was continued for 56 yards farther, in the hope that the coal would come in again, but it proved only a continuous band of stone, 3 feet thick.

The roof and floor of the seam continued unchanged over the barren area, but a boring put up through the measures above the coal proved that the overlying rock, which is usually white, was very red and quite thick. The following account of the borings is furnished by Mr. Platt:—

[1] Communicated by permission of the Director of H.M. Geological Survey.

Fig. 1.—*Section at Wirral Colliery, Neston.*



ASCENDING SECTIONS ABOVE THE SEVEN-FEET SEAM.

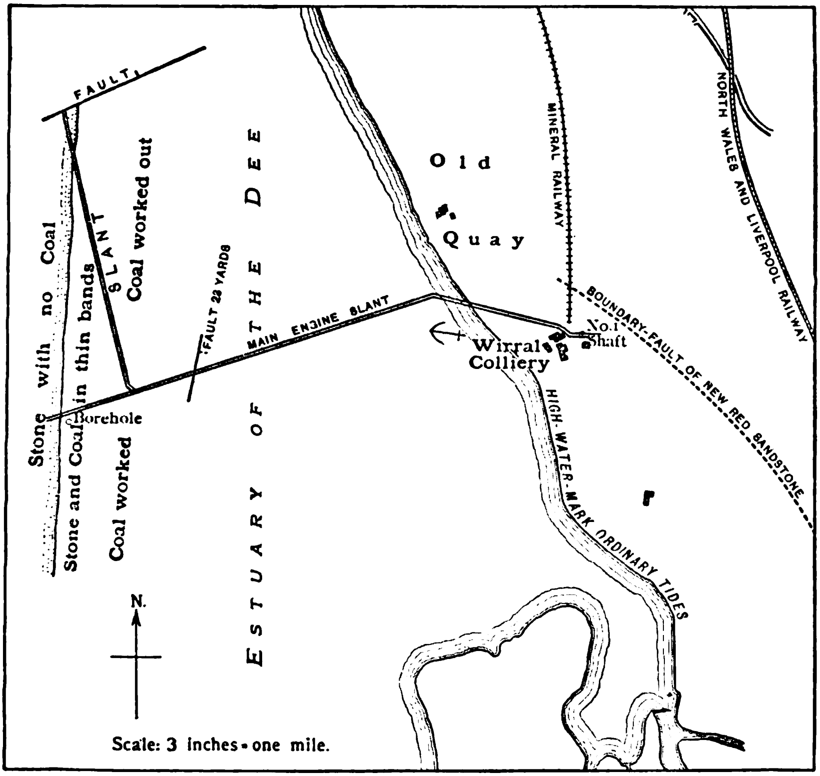
Boring No. 1, where the change to stone takes place.

	Feet.	Inches.
Black bass [carbonaceous shale]—roof of Seven-Feet Coal.	4	0
Blue metal [shale]	42	6
Rock, very red	21	0
Dark blue metal, with ironstone-bands	15	6
Rock—bluish-grey	2	6
A change of strata from bluish-grey to very red with pockets of red ore. Stopped boring	2	0
	87	6

Boring No. 2, 300 yards nearer the shaft than No. 1.

	Feet.	Inches.
Black bass—roof of Seven-Feet Coal	4	0
Blue metal	45	3
White rock	18	6
Blue metal	10	6
Warrant [fireclay]	8	0
Coal	5	5
	91	8

Fig. 2.—*Plan of Wirral Colliery.*



In a third boring, 300 yards from No. 2, but on the same level, the same strata were proved, but no coal was found.

The red colour of the rock in No. 1 boring is no doubt due to staining by the New Red Sandstone, which probably lies at no great distance overhead, and in fact may have been touched in the uppermost 2 feet of the bore-hole. Presumably it rests naturally, though unconformably, upon the Coal-Measures, for some old pits north of the colliery proved red rocks, some of which seem to have been stained Middle Coal-Measures, while others are said to have been New Red Sandstone. East of the colliery the New Red Sandstone is thrown in by a fault.

Explorations were then carried on to the north and south of the main engine-slant (see fig. 2, p. 299). In the former direction the coal has been worked for a distance of 980 yards, and in the latter for 500 yards, so that the boundary of the barren area has been proved for a distance of 1480 yards. The boundary runs almost straight in a north-and-south direction, but at present there is no further clue to the size or shape of the barren area. No similar change has been seen in any of the seams, either in Flintshire or South Lancashire.

The stone, when first worked, is hard and black; but after exposure to the weather or washing with dilute acid much of it becomes grey and displays various structures. The most conspicuous variety is that described as consisting of small pellets. This is a pisolite composed of spherules ranging from about $\frac{1}{16}$ to $\frac{2}{16}$ inch in diameter (E 3270[1]: see Pl. XII, fig. 1). The spherules are generally in contact and mutually interfering, so that the mass presents a botryoidal or mammillated appearance; but sometimes they are isolated, and the intervening spaces are filled with coaly matter. When cut across they show a radiate crystalline structure, with less clear concentric rings. Coaly matter occurs in them, and crystallization has obviously taken place in water containing coaly matter in suspension. They effervesce sluggishly with cold acid, and leave a somewhat copious residue, consisting in part of crystals arranged in bunches or films which have obviously formed part of the radiate structure, and in part of brown or amber-coloured films of doubtful origin, but which may be thin pellicles of coaly matter. The coaly matter between the spherules also partly breaks down in acid, and leaves a residue consisting chiefly of the brown filmy material with some crystalline matter. In hot acid the crystals disappear with effervescence.

An analysis of this rock by Dr. Pollard shews that it is a dolomite of almost theoretically pure composition, with the addition of some coaly matter, a little iron, and a not inconsiderable residue chiefly made up of silica and alumina. The residue is no doubt clastic material, and probably occurs in the spaces between the spherulites as a coaly mud. The complete analysis is tabulated on p. 303.

[1] The numbers in parentheses (E 3270, &c.) are those affixed to the slides in the Geological Survey Collections at Jermyn Street, London.

Another variety of the rock (E 3280: see Pl. XII, fig. 2) is built up of small masses or short irregular layers of crystalline matter, separated by very irregular patches of fine mud, in which minute grains of quartz and mica are recognizable. The layers have been irregularly deposited, some upon the surface of an inclusion of mud, others upon previously formed crystalline material, but the principal axes of the crystals are always at right angles to the surface of deposition. This rock differs from the pisolite merely in the fact that the dolomite has tended to coat irregular surfaces, whereas in the pisolite it has crystallized round a number of independent centres.

The analysis of this rock is tabulated by Dr. Pollard on p. 303. The ignited residue amounts to 23·68 per cent., and shews the presence of alkalies, derived no doubt from the mica; the large residue is probably due to the inclusions of mud referred to above.

Another specimen (E 3344 & 3345: see Pl. XII, fig. 5) consists partly of woody tissue filled with dolomite. It includes also thin bands of coal, which however have been broken up and recemented by dolomite. The perfect angularity of the fragments shews that the coal had hardened before it was broken, and it is possible that the brecciation was subsequent, like some cracks which traverse the original structures in many of the slides. It should be remembered, however, that fragments and pebbles of coal are not uncommon in Coal-Measure conglomerates, shewing that hardening followed rapidly upon deposition. The fragments of woody tissue, after removal of the dolomite by acid, yield a copious residue of minute carbonized vegetable fibres.

Dr. Pollard's analysis of this specimen, tabulated on p. 303, proves that it is approximately pure dolomite, with the addition of 17·80 per cent. of coaly matter and 5·38 per cent. of ferrous oxide. The ignited residue, on the other hand, is extremely small; the coaly matter may be attributed to the vegetable tissue, and the specimen may be regarded as being made up of fragments of wood impregnated with, and cemented together by, dolomite.

Other specimens shew small masses and films of coaly matter, not displaying any trace of organic arrangement, but tending to split up and ramify irregularly through a dolomitic matrix (E 3279 & E 3281: see Pl. XII, figs. 3 & 4). Crystallization has evidently taken place in the presence of coaly matter, but the dolomite in crystallizing out has rejected the mud and split it up into an infinite variety of feathery forms.

The phenomena are not those of a 'wash-out.' In such a case the coal, together with some of the associated strata, has been washed away immediately, or soon after deposition, and its place taken by sand, gravel, or mud, the erosion having obviously been due to running water. In the Wirral dolomite not only is there no sign of erosion, but there is proof that it was formed in almost

motionless water. Clastic material is extremely scarce, and when present (E 3280: Pl. XII, fig. 2) is so fine as to be recognizable with difficulty. In many of the specimens there is practically no mud. The vegetable débris are finely divided, and even after mineralization take long to settle; before mineralization they must have been in a condition to travel with the smallest movement in the water. For the dolomite no more current would be required than would suffice to bring to the spot fresh supplies of the carbonates in solution. The irregularity of the structures and the absence of lamination point also to tranquillity; the irregularities of the surface were accentuated rather than smoothed over by the successive layers of crystalline and coaly matter.

The conditions, therefore, were those under which a tufa would be formed—a mode of origin to which the structure and character of the rock also point. The formation of tufa is generally confined to shallow water, and is attributed theoretically to chemical action. More frequently it is due probably to the absorption of carbon-dioxide by algæ, and to the reduction of the bicarbonates to the less soluble carbonates. In the case under consideration the presence of vegetable matter would tend to prevent the precipitation, if carbonic acid were evolved; but from a general consideration of the character of coal-seams there is reason to think that the vegetable matter of which they consist was preserved from decomposition by being wholly submerged. There is no reason to doubt that the shreds of vegetation which reached the dolomitic region were fully submerged.

The presence of magnesium-carbonate is somewhat unusual in tufas. The fact that the measures are, or have been, overlain by the New Red Sandstone suggests the possibility of the tufa having been originally calcareous and subsequently dolomitized, but limestones lying immediately below Triassic beds often show no dolomitization. On the other hand, Coal-Measure waters themselves are strongly mineralized with salts of lime, magnesia, iron, and less commonly of baryta and soda. It seems, therefore, more probable that the composition of the tufa was due to the character of the water in which it was formed, than to the subsequent introduction of carbonate of magnesia.

The supposition that the deposit marks the site of a spring of Coal-Measure age is negatived by a consideration of the physical conditions of the period. There is evidence that the coals were formed at or below sea-level, and that there was certainly no high ground, and probably none above sea-level, within some miles of the spot. Under the circumstances there would be nothing to force the water up from the strata underlying the seam.

A coal-seam may be regarded as the last phase of an episode of sedimentary activity.[1] The Coal-Measures, though on the whole a most irregular deposit, are built up of repetitions of a certain definite sequence of deposits, sandstone or conglomerate being succeeded by shale, shale by coal. By a repetition of this sequence each coal

would be overlain by a sandstone, and as a matter of fact this relation of coal to rock is found to hold in the majority of cases. Sedimentation therefore was spasmodic; it was at its maximum when the sandstones were being formed, and it was approaching the vanishing point when only vegetable matter, almost free from mineral material, was being distributed. The dolomitic tufa of the Wirral Colliery seems to carry us a stage farther. It was formed on a spot to which clastic material scarcely gained access, and which was reached even by vegetable matter in scant quantity and in finely-divided form.

The nearest approach to the spherulitic dolomite that I have seen is a rock from North Staffordshire shewn to me by Mr. Gibson. It occurs in bands and nodules in marls between the Deep Mine Ironstone and the Knowles Coal at Fenton Park, and was described by Mr. Teall in the Summary of Progress of the Geological Survey for 1898, p. 127, as a sphærosiderite (E 3214). In structure it closely resembles the Cheshire spherulitic specimen, but differs in the spherulites consisting of carbonate of iron instead of dolomite, and in the fact that coal fills the interstitial spaces in the Cheshire specimen.

It has long been known that coals are replaced by ironstones, and ironstones by limestones. The origin of iron-ores by the replacement of carbonate of lime has been proved in other rocks, but I am unaware of satisfactory evidence that such was the history of any of the Coal-Measure iron-ores. The Cheshire example is unique, in the fact that the place of the coal is taken by dolomite, and that the change takes place within a distance of a few yards.

Chemical Analyses by William Pollard, M.A., D.Sc., F.G.S.

	E 3280.	E 3270.	E 3344–45.
	Per cent.	Per cent.	Per cent.
Residue (ignited)[1]	23·68	11·02	0·33
Al_2O_3 + trace of P_2O_5	0·34	0·15	0·34
FeO	2·26	0·60	5·38
MnO	0·33	not estimated	0·33
CaO	21·51	26·21	24·89
MgO	14·33	18·49	13·23
CO_2	33·23	40·49	36·36
Coaly matter	4·09	2·99	17·80
H_2O at 105°	0·55	0·45	1·29
SO_3	trace	0·15	0·70
Totals	100·32	100·55	100·65

[1] Part insoluble in boiling dilute hydrochloric acid.

The insoluble residue of E 3270 contained:—

	Per cent.	
SiO_2	51·6	91·3
TiO_2	1·0	
Al_2O_3	35·5	
Fe_2O_3	3·2	

Alkalies and small quantities of lime and magnesia not estimated.

The insoluble residue of E 3344-45 contained silica, iron, alumina, and lime. Sufficient material was not available for quantitative estimation.

The ignited insoluble residue of E 3280 was composed of:—

	Per cent.	
SiO_2	64·51	100·65
TiO_2	1·24	
Al_2O_3	26·27	
Fe_2O_3	2·32	
CaO	0·62	
MgO	0·89	
K_2O	4·41	
Na_2O+trace of Li_2O	0·39	

The ratios of iron, lime, magnesia, and carbon-dioxide in the soluble portions of the three specimens are:—

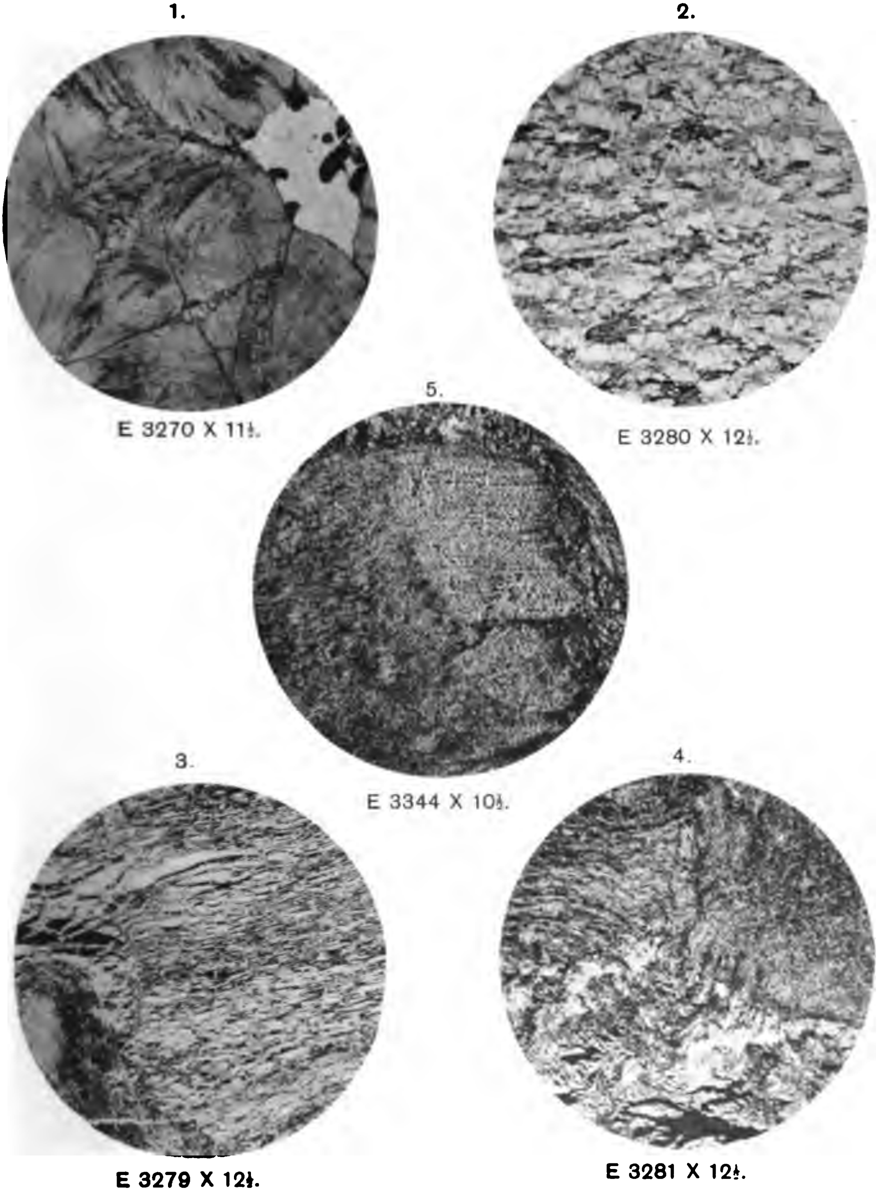
	CaO.	FeO.	MgO.	CO_2.
E 3280	1	·08	·92	1·97
E 3270	1	·02	·96	1·97
E 3344–45	1	·17	·74	1·86

EXPLANATION OF PLATE XII.

Fig. 1. E 3270×11½. Spherulitic dolomite.
2. E 3280×12½. Irregular layers of dolomite, with patches of mud.
3. E 3279×12½. Films of coaly matter ramifying through dolomite.
4. E 3281×12½. Similar to the preceding, but with a fragment of wood.
5. E 3344×10½. Woody tissue impregnated with, and cemented together by, dolomite.

Discussion.

Mr. Hudleston complimented the Author on the very graphic description that he had given of a phenomenon, which, fortunately for the interests of coal-owners in general, is said to be without parallel in our islands. Accepting the facts as detailed by the Author, the question of the causes leading to this singular passage of coal into dolomite is certainly one of considerable difficulty. He (the speaker) could remember the time when the origin of coal-seams was generally held to be due to vegetable growth *in situ*, each seam having its appropriate underclay: persons holding contrary opinions did not meet with much favour at the Geological Society. Undoubtedly, the origin of coal-seams need not have been the same in all cases. In this case the Author had adopted the view that coal is due to sedimentation, where particles of organic origin play the part of mineral clastic materials, such as make up the sands and clays of the Coal-Measures; and he was disposed to regard the failure in the supply of this clastic material of vegetable origin as the cause of a void which had been filled up by contemporaneous tufaceous deposits. Herein lay the great difficulty: how were we to account for the



Microscopic Sections, illustrating the Passage of Coal into Dolomite.

A. Strahan, Photomicrogr. *Bemrose, Collo.*

almost total disappearance of clastic material of vegetable origin within the space of 400 or 500 yards? It was not absolutely necessary to offer an alternative view. The objections to any theory involving the replacement of coal by dolomite were very great, while the question itself was essentially one for chemists. Nevertheless, an explanation in this direction should not be regarded as impossible: the peculiar reddening of the measures above the dolomitic stone was worthy of attention in this connection.

Dr. Cullis said that the mode of origin which the Author had suggested for this peculiar band of dolomite seemed to him to be a very likely one, for it appeared to explain the facts in a satisfactory manner. Bearing in mind the probable nature of the waters in which the Coal-Measures accumulated, their direct derivation from the land, their shallowness, and the constant and rapid evaporation to which they were doubtless subjected, it did not seem improbable that occasionally the carbonates of calcium and magnesium, which they carried in solution, might be precipitated in the form of magnesian limestones or of dolomites. There seemed to be at least two distinct methods in which sedimentary dolomites (as distinguished from crystalline dolomites which have acquired their crystalline texture as the result of metamorphism) had originated: firstly by contemporaneous precipitation from solution, and secondly by the substitution of magnesium for a part of the calcium in a normal limestone by a process of subsequent replacement. The rock described by the Author, and also the Permian Magnesian Limestone (which exhibited structures not at all unlike those displayed by the dolomite-band under discussion), might be examples of rocks originating essentially by the first of these processes; while the dolomitic parts of the Carboniferous Limestone or of recent coral-reefs might be instanced as examples produced by the second. Students of dolomites were indebted to the Author for having recorded this occurrence of a rock which, though apparently rare, perhaps unique, in British deposits, was nevertheless one which from *a priori* considerations might very reasonably have been expected to occur.

Mr. Walcot Gibson stated that the spherulitic siderite referred to by the Author occurred in large quantities in North Staffordshire, either aggregated into bands and nodules, or disseminated throughout the marls and clays of the upper portion of the Middle Coal-Measures and of the lower part of the so-called Upper Coal-Measures. In the latter, the well-known Black-Band Ironstones were developed: these contained a considerable amount of vegetable and organic matter. It was a recognized fact that the Black-Band Ironstones invariably overlay coals, the ironstone varying in thickness in inverse ratio to the thickness of the coal. In the western part of the Pottery Coalfield, in the Minnie shafts, the ironstones appeared to be replaced in part by limestones. It was extremely likely that the phenomena described by the Author were present in the upper part of the Coal-Measures in North Staffordshire, and that rocks of the type described in the paper were formed over large areas in the Midlands during the closing stages of the Coal-Measure Period.

Mr. R. D. Oldham considered that the paper was one of great

interest, from its bearing on the origin of coal. His own observations of coal-seams in India had led him to question the origin of those seams by growth *in situ*; and though he held no fixed opinion regarding this, he favoured what was known as the 'drift-theory.' He feared, however, that the Author's paper would in future be quoted as the strongest piece of evidence that had been produced in favour of the growth-*in-situ* theory; for while it was easy to understand how a calcareous or other mineral deposit could be formed under water in, or on the margins of, a forest or a bog, it was difficult to understand how such easily transported débris as vegetable matter could so abruptly cease and give way to a mineral deposit, as had been described by the Author, if the coal had originated by subaqueous deposition. The instances quoted by the previous speaker did not appear to be strictly analogous, as they were cases of one stratum thinning out and an adjacent one thickening, the two retaining their distinctness; but if he correctly understood the paper, in the condensed form as read, there was here not a thinning-out of the coal and a thickening of the dolomite, but a transition in the mineral character of the bed, which seemed more easily explicable on the theory of growth *in situ*, than on the drift-theory of the origin of coal.

The PRESIDENT also spoke.

The AUTHOR, in reply to Mr. Hudleston, remarked that the vegetable matter constituting a coal-seam differed from other sediments in its capability of remaining longer in suspension. The coal and the dolomite were most intimately connected; for the dolomite appeared first as thin streaks in the seam, and it was only by the gradual expansion of these that the coal was finally replaced. The Permian rocks were not developed in that part of the country, and the New Red Sandstone rested directly upon the Coal-Measures. With respect to dolomitic tufas, it seemed to him that the Magnesian Limestone might itself be so described: it was difficult to see from what source the dolomitization of that rock could have proceeded subsequently to its formation. Several of the limestones described by Mr. Gibson contained organisms, some of them in great abundance: none had been found in the Wirral dolomite. So far the exploration had disclosed a rock of fairly constant composition, but the dolomite might be found to pass into an ironstone at any moment, in which case the parallel with some of the Staffordshire rocks would be nearly complete. On the drift-theory of the origin of coal, referred to by Mr. Oldham, it might be supposed that the dolomite was formed in an area which even drifting vegetable matter failed to reach, owing to stagnation in the water. There was no margin to the area comparable with the bank of a pond. It was true, as remarked by the President, that there were many recognizable fragments of wood; their occurrence in unusual number might have been due to their having floated beyond the limit reached by the thoroughly macerated vegetable matter. The coaly seams in the rock showed no unusual characters.

23. FOSSILS *in the* OXFORD UNIVERSITY MUSEUM, V: *On the* STRUCTURE *and* AFFINITIES *of the* RHÆTIC PLANT NAIADITA. By Miss IGERNA B. J. SOLLAS, B.Sc. (Lond.), Newnham College, Cambridge. (Communicated by Prof. W. J. SOLLAS, D.Sc., LL.D., F.R.S., F.G.S. Read February 6th, 1901.)

[PLATE XIII.]

THE Rhætic plant-remains known as *Naiadita* are found in a narrow area stretching down that part of the Severn Valley which lies below the Avon. Phillips [1] mentions their occurrence at Pylle Hill, Bristol, and associated with *Estheria* at Garden Cliff, Westbury-on-Severn, and Wainlode Cliff, Tewkesbury. The exact horizon of these plant-beds is that which Edward Wilson named Bed K.

The vertical thickness of rock, through which the plants are distributed in layers of extreme tenuity, is 7 inches at Tewkesbury and 9 inches at Westbury-on-Severn.

These fossils are well-known, from the description published fifty-one years ago by James Buckman [2]; but the first discoverer was P. B. Brodie,[3] who chose for them the name *Naiadita* because Lindley considered them to be monocotyledonous plants resembling the members of the order Naiadaceæ. Mr. J. Starkie Gardner [4] re-examined them, and pointed out that the markings supposed by Lindley to have been left by the rectangular venation of a *Naias*-like leaf, were in reality fossilized cell-walls. Mr. Gardner concluded that the plant was a moss and was probably closely allied to the genus *Fontinalis*. He spoke of a capsule, but of this he gave no description.

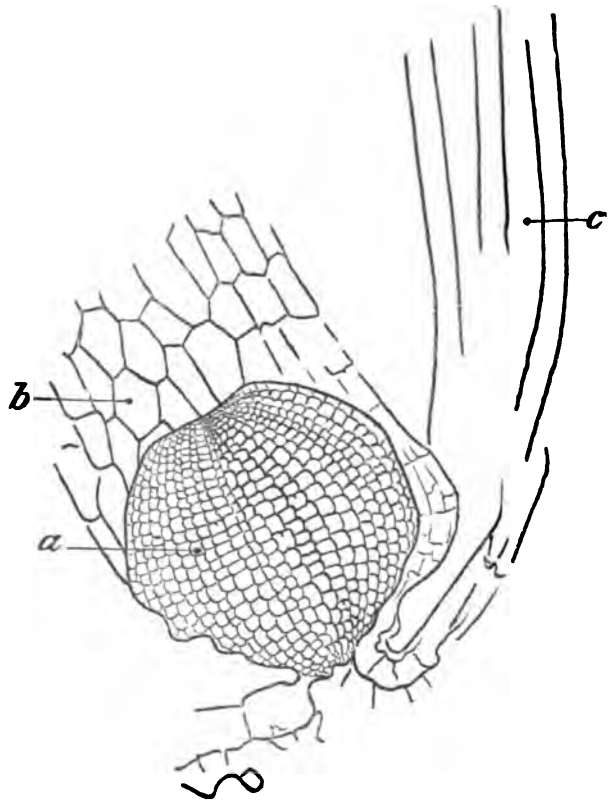
A slab from the *Naiadita*-bed of Pylle Hill, Bristol, was recently sent by Mr. W. H. Wickes of that city to my father for examination,[5] because it contains bodies which were thought to be possibly gemmules of a sponge. On this proving not to be the case, the specimen was handed over to me. I have since had the advantage of studying additional material, owing to the kindness of Mr. A. C. Seward and Mr. Wickes.

The plant, which was delicate, slender, and moss-like in habit, is preserved in a more or less fragmentary condition. The state of preservation varies, however, in the different strata. Some of the strata contain loose leaves and disconnected pieces of stem only, while in others the stems may branch, the leaves are still attached to the stem, and sporangia are present also, at least occasionally attached. The sporangia are situated at the bases of leaves which embrace them ; but whether they are terminal, or are borne laterally on the stems, is somewhat difficult to decide. It is a point which

[1] 'Geology of Oxford' 1871, pp. 102–105.
[2] Quart. Journ. Geol. Soc. vol. vi (1850) p. 415.
[3] 'Fossil Insects' 1845, pp. 92–93.
[4] Geol. Mag. 1886, pp. 203, 495.
[5] Proc. Bristol Nat. Soc. vol. ix (1901) pp. 100, 102.

could probably be determined by grinding with a hone, a process which I shall describe presently. Text-fig. 1, obtained by this method, certainly seems to attest to a lateral position, and though the sporangium seen in Pl. XIII, fig. 1 appears terminal, it is obviously not necessarily so, as a continuation of the stem beyond the sporangium may easily have been broken away. Moreover, from the repeated occurrence of sporangia at a point of branching of the stem, it seems likely that this may be a natural situation.

Fig. 1.—*Sporangium* (a) *in the axil of a leaf* (b) *of* N. lanceolata. *(×40.)*



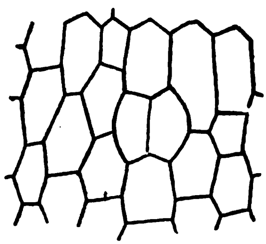
[Both *a* and *b* are attached to a stem. Owing to the unevenness of the rock-surface which was ground, the sporangium and leaf are entire, while the stem is seen in section, *c* being the thin-walled tubes of the stem, described below and seen again in fig. 3, p. 310.]

The shapes of the leaves are various, and this led James Buckman to distinguish three species, namely, *N. lanceolata*, Brodie, *N. petiolata*, and *N. obtusa*. Now, pieces of stem are not uncommon which

combine the characters either of *N. lanceolata* and *N. petiolata*, or of *N. lanceolata* and *N. obtusa*: that is to say, these stems each bear leaves of two kinds, the shapes of the leaves being those described by the specific names and well figured in Buckman's paper. Hence I propose to retain only one specific name, and this must be *lanceolata*, that of the type, which by good fortune is the most frequently truly descriptive.

The surface of the leaves shows clearly the outlines of the epidermal cell-walls. The cells are long and rectangular, often shortening towards the bases of the leaves. No stomata are to be seen, but in searching for these structures an arrangement of cells like that shown in fig. 2 frequently arrests attention; to this, however, I attach no special significance.

Fig. 2.—*Portion of a leaf of* N. lanceolata, *showing the arrangement of the cell-walls.* (× 40.)



The capsules are more or less spherical and short-stalked. The more perfect specimens have a wall which appears tessellated, as it is composed of small quadrate cells (fig. 1, p. 308). The larger capsules measure about 0·75 mm. in diameter.

Sections of the capsules show that the spores are still connected into tetrads (Pl. XIII, fig. 6). The spores may be dissolved out from the rock by dilute hydrochloric acid. They are then seen to be tetrahedral, with a triradiate mark. There are two spore-coats: the exine, which is covered with irregular bosses, and the intine, which is smooth. The outer face of the tetrahedral spore is rounded, and at its junction with the three pyramidal interior faces, both exine and intine are extended to form a marginal rim (Pl. XIII, figs. 8–10). This is distinguished in the case of the exine by greater thickness and coarser tuberculation than the rest of the membrane. The spores measure 0·08 mm. in diameter, and are thus at least twice as large as the spores of any recent species that has fallen under my examination.

The minute structure of the vegetative parts, so far as it is at present preserved, may be studied in successive sections exposed with the aid of a hone of Water-of-Ayr stone. This is a simple but laborious process, involving a considerable expenditure of time. Unfortunately, the stems are too thin to admit of the use of a machine, so that sections cannot be taken at regular and measured intervals. A slab is chosen that is known to contain a plant-bearing layer close beneath one surface. This surface is then ground until fragments of plant-tissue are seen through the thin film of rock covering them. The grinding is then proceeded with very slowly. If one is fortunate, there will be among the fragments one or more pieces of stem, possibly with leaves attached.

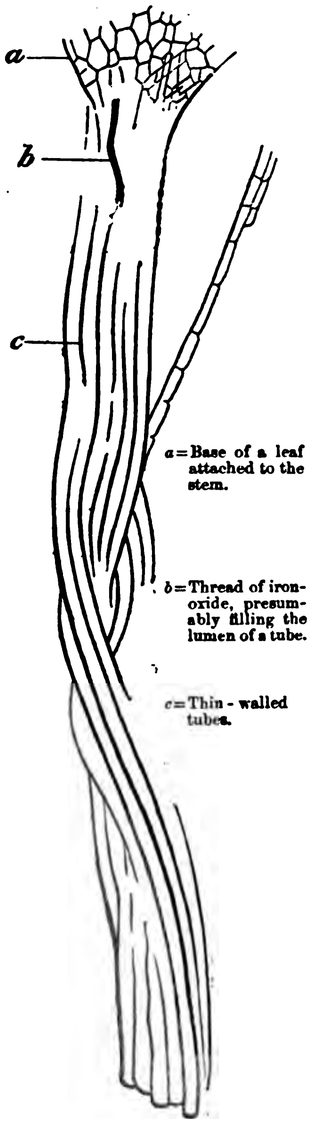
Confining our attention to such a stem, one sees first the epidermis composed of long rectangular cells. A few strokes of the hone suffice to remove this layer, exposing to view a number of thin-walled tubes of rather wide lumen running longitudinally in the stem (fig. 3). They lie for the most part parallel one to the other, but are often frayed out at the broken ends of the stem; and in a few cases I have seen a single one of them passing into the base of a leaf. No scalariform markings, or indeed regular markings of any kind, occur on the walls of these tubes, which appear to be mere films of granules of iron-oxide of various sizes. Among these wide tubes are occasionally fine threads of iron-oxide, which, if they may be assumed to be casts, bear witness to the existence of vessels of a narrower lumen also. When by further grinding the vessels are removed, the epidermis of the other side of the stem alone remains.

The leaves, when seen in vertical section, show only a single layer of complete cells; while irregular remains of cell-walls are attached to the morphologically lower surface of this layer.

The nature of the sporangia, their position at the bases of leaves, and the characters of the spores, all suggest that *Naiadita* would be more naturally associated with Lycopodiales than with the Musci. Vegetative characters are generally recognized as of little value in distinguishing these groups; but I think that such evidence as is afforded by them is at any rate not conflicting with that furnished by the reproductive organs.

The absence of stomata in a plant, which we propose to regard as of sporophytic nature, calls for con-

Fig. 3.—*Sketch based on a* camera-lucida *drawing of a section of a stem of* N. lanceolata. *(×18).*



sideration; and the absence or non-preservation of cortical tissue seems to be a feature in stem-structure sharply contrasting with that typical of the Lycopodiaceæ.

In connection with both of these characters it is important to recognize the probability that *Naiadita* was a submerged species. This Mr. Starkie Gardner has already maintained, on the evidence of the associated freshwater fossils and that of the general habit of the plant itself. On *a priori* grounds one might feel safe in assuming that stomata would necessarily be absent in any submerged plant: they are absent in subaquatic phanerogams, whether the submerged habit be newly acquired or long established; and that submergence may produce the same effect upon a cryptogamous plant is shewn by *Isoetes*. Moreover, their normal function is bound up with a subaërial life. Hence it was with no little surprise that in examining the leaves of the only recent submerged *Lycopodium* (namely, *L. alopecuroides* var. *aquaticum*) I found unmistakable stomata.[1] The leaves of this variety consist of a single layer of fairly stout-walled rectangular cells—the upper epidermis—and of one or two layers of excessively thin-walled cells, the outermost of which is the lower epidermis, in which the stomata are situated. The actual existence of this structure in the leaf of a recent lycopod strengthens the probability of the interpretation of the single layer of leaf-cells in *Naiadita* as the only preserved representative of a many-layered leaf. At the same time the situation of the stomata in a delicate layer of cells, which would have escaped preservation, affords an alternative explanation of the absence of stomata in *Naiadita*.

As regards the stem of this recent aquatic variety of *Lycopodium*, the cross-section of the cortex is identical with that of a reconstruction which I had already drawn of the stem of *Naiadita*. The arrangement of the tissues is that of *Selaginella* carried to extreme. The whole cortical tissue from epidermis to stele is replaced by an air-space traversed by delicate trabeculæ of thin-walled cells. Curiously the preservation is not good enough to admit of an attempt to reconstruct the stele. The most that can be said is that it appears to have contained a band-like xylem-plate, the elements of which had for the most part a wide lumen.

If we may accept the affinities here suggested for *Naiadita*, we have in this plant the earliest recorded instance of a fossil member of the Lycopodiaceæ, resembling in proportions and outward morphology the existing representatives of the group, but separated from them by the whole extent of the Mesozoic and Tertiary Epochs.

[1] A. Braun has pointed out that several submerged species of *Isoetes* bear stomata on the leaves. See Sitzungsber. d. k. preuss. Akad. d. Wissensch. 1863, p. 547: quoted by Scott & Hill, Ann. Botan. vol. xiv (1900) p. 443.

EXPLANATION OF PLATE XIII.

Fig. 1. Part of a stem of *Naiadita lanceolata*, Brodie, bearing a sporangium and leaves. (× 2.)
2. Pieces of stem of *N. lanceolata*, bearing leaves of various forms. (× 2.)
3. Small portion of stem of *N. lanceolata*, with leaves more highly magnified. (× about 6.)
4. Sporangium of fig. 1. (× 10.)
5. Part of a section of a sporangium, to show the wall and the contained spores. (× 180.)
6. Part of a section of a sporangium, showing spore-tetrads. (× 180.)
7. An isolated spore-tetrad, dissolved out from the sporangium by hydrochloric acid, and mounted in balsam. (× 180.)
8. A single spore seen edgewise, showing the marginal rim crossing the spore as a dark band. (× 180.)
9. A single spore seen *en face*, surrounded by the marginal rim. (× 180.)
10. Part of a spore, showing the general tuberculation of the surface and the large peg-like tubercles of the rim. (× 180.)

Discussion.

Mr. Strahan remarked that it was of much interest to know whether this plant grew in fresh or salt water. The Authoress had described it as being associated with *Estheria*, but according to the late Edward Wilson & Mr. Wickes it occurred in the same bed with marine forms, such as *Cardium rhæticum* and *Pecten valoniensis*. The interest lay in the fact that the *Naiadita*-bed occupied about the same horizon as certain thin bands recently observed in South Wales. There some red and green marls of typical Keuper aspect occurred above the *Avicula-contorta* Shales, and clearly indicated a temporary recurrence of Keuper conditions long after the first incursion of the Rhætic marine fauna.

Mr. H. W. Burrows also spoke, and Prof. Sollas replied on behalf of the Authoress.

Fig. 5.

Fig. 3.

Fig. 1.

Fig. 7.

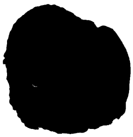


Fig. 2.

Fig. 8.

Fig. 6.

Fig 9

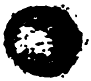


Fig. 4.

Fig. 10.

I B. J. Sollas, photomicrogr.

NAIADITA.

Bemrose, Collo.

24. *On the* CRUSH-CONGLOMERATES *of* ARGYLLSHIRE. By JAMES BASTIAN HILL, Esq., R.N. (Communicated by R. S. HERRIES, Esq., M.A., Sec.G.S.[1] Read May 22nd, 1901.)

[MAP on p. 316.]

CONTENTS.

I. INTRODUCTORY.

IN a former communication to this Society[2] dealing with the Dalradian schists of Argyllshire, I described a deposit known as the Boulder-bed, which occurs in the Highland Series along a horizon extending from Aberdeenshire to Islay. I pointed out that this abnormal conglomerate owed its origin to aqueous deposition, and supported that contention by showing that, in various localities along its outcrop, it contains boulders of foreign material.

At that time, with the exception of the Isle of Man, where the phenomena of crush-conglomerates had been brought to light by the researches of Mr. G. W. Lamplugh, the occurrence of pseudo-conglomerates had not been recorded in Britain. My subsequent work, however, on the Geological Survey in Cornwall, revealed their existence in that county on a large scale; this was described in the Summary of Progress of the Geological Survey for 1899 (pp. 89 *et seqq.*), and in a paper read before the Geological Society of Cornwall last November.[3] On continuing my work in the Highlands last summer I was able to show that these structures occur in Scotland among the Dalradian Series, where they bear so marked a resemblance to many portions of the Highland Boulder-bed that they may readily be confounded together, especially as they are both met with on the same horizon.

In my above-mentioned communication to this Society, I sought to demonstrate that the typical crystalline schists of the Central Highlands, when followed into the Loch Awe Basin, pass laterally into sediments which are comparatively unaltered. Having shown the passage of the more important stratigraphical zones from the Loch Awe region into the Central Highlands, I pressed the argument still further by showing that the Highland Boulder-bed is met with in both areas occupying the same stratigraphical position. Although it was pointed out that from Aberdeenshire in the east to Islay in the extreme west, foreign boulders (mainly of granite) had been

[1] Communicated by permission of the Director of H.M. Geological Survey.
[2] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 470-92.
[3] Trans. Geol. Soc. Cornw. vol. xii, pt. vi (1901) p. 403.

observed in this conglomerate-deposit by my colleagues, no such boulders had then been detected by me in that part of the deposit which is located in the Loch Awe Basin. Since the date of that paper, however, Mr. H. Kynaston, while continuing the examination of this deposit, has completed the chain of evidence by discovering similar foreign boulders in the latter area. My argument, therefore, in so far as it was based on the continuity of the Highland Boulder-bed, remains valid, notwithstanding that crush-conglomerates may have been mistaken for the former in some of the localities cited by me in that paper.

The object of the present communication is not only to extend my former description of the Loch Awe area, and to record the occurrence of crush-conglomerates in the Highlands of Scotland, but to enforce the deductions of Mr. G. W. Lamplugh, by insisting that these pseudo-structures have a more prominent position in rock-building than their recorded occurrences would lead us to suppose. In areas like that described by Mr. Lamplugh in the Isle of Man, and by myself in Cornwall, elucidation of these phenomena requires a longer and more intimate acquaintance with local geological structures than the ordinary observer cares to acquire, and descriptions, however lucid, may fail to carry conviction where direct proof is wanting. In Argyllshire, fortunately, the case is different, as I am able to demonstrate that boulders of the crush-conglomerates are of later age than the matrix in which they lie, an argument from which the most sceptical mind will find escape difficult.

II. General Description of the Area.

The area in Argyllshire in which these crush-conglomerates have so far been detected, comprises a small belt of country to the south-west of Loch Awe, of about 10 square miles; but as the Survey progresses they will probably be found to occupy a more extended horizon.

Before entering into a discussion of these structures it will be necessary to give a brief outline of the rocks which make up the district, more especially of those in which these characters are displayed.

The sedimentary rocks met with include all the members of the Loch Awe Series, consisting of grits, slates, and limestones, with which are associated enormous masses of igneous material of Dalradian age, ranging in composition from intermediate to basic, while dykes of porphyrite, of later date (probably of Old Red Sandstone age), are occasionally met with. Finally, a plexus of Tertiary dykes of basaltic type traverses the country in a north-westerly direction, at right angles both to the strike of the sediments and the foregoing igneous rocks associated with them.

The members of the Loch Awe Series call for no detailed description, their characters having been described in my former communication to this Society.[1]

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 470–92.

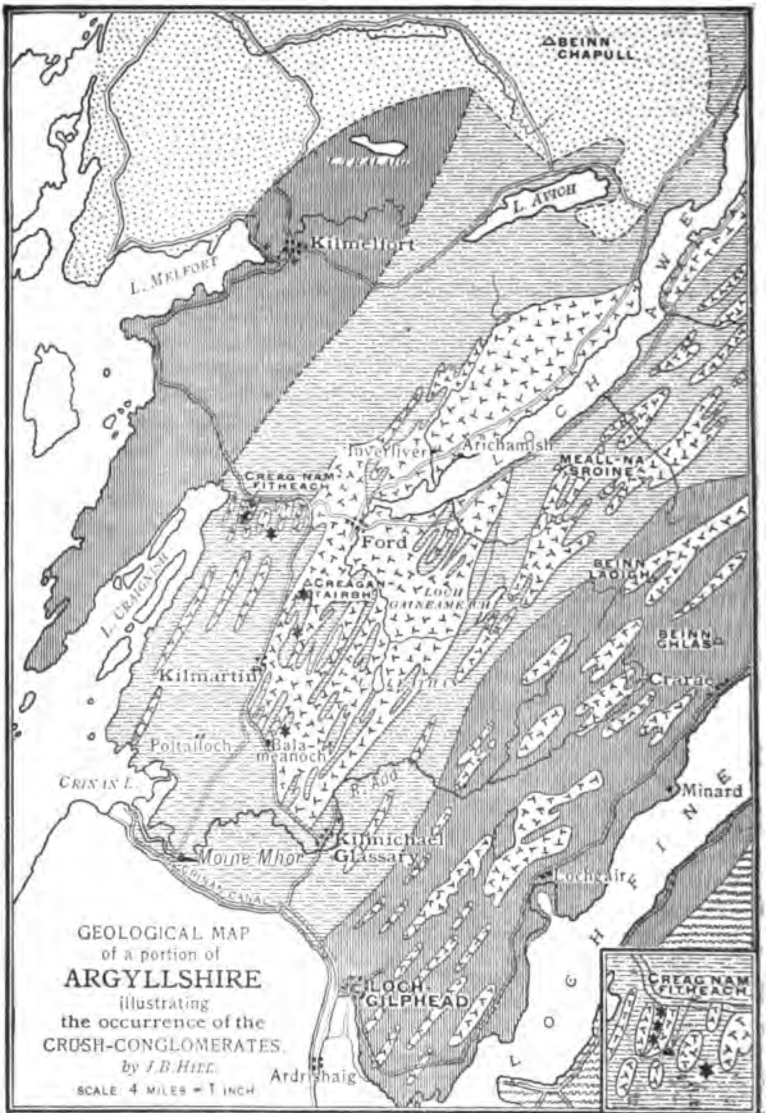
The limestone at the base of the series is extremely variable in character, ranging, in the same exposure, from a coarse calcareous grit to a dark calcareous slate, with a normal limestone as an intermediate stage, while occasionally a band of quartzite may be seen associated with it. In its normal condition it is generally crystalline and blue in colour. Crystals of nearly black calcite are sometimes present, giving the rock a darker hue. In its gritty condition, which is very common in this area, the limestone-matrix contains numerous grains of blue quartz, and felspars often red, which may exceptionally reach an inch in length. The quartz-grains may frequently be seen in the normal, fine-grained, compact limestone.

Black slates are associated with the limestone, and by the accession of calcareous matter often merge into it. The grits which are at the top of the series sometimes shade imperceptibly into the gritty limestones. These normal grits often contain zones so coarse as to approach the condition of conglomerates, the pebbles of quartz and felspar being as large as almonds, with which finer-grained grits and grey quartzites are associated.

We occasionally see sediments of a greenish hue due to the accession of chloritic matter in their composition, but these greenish grits and slates pass into, and are clearly associated with, those of normal type. It is not uncommon to find pebbles of quartz and felspar embedded in a green slate-matrix, and green calcareous beds are sometimes associated with the limestones.

The rocks are everywhere folded, the folds being of isoclinal type and very steep, often even vertical. The bedding is, on the whole, not far from the horizontal, with nearly vertical foliation. In fact the members of the Loch Awe Series are here lying in a gentle trough of the Ardrishaig Series which they succeed, and while such indications as are afforded by dip and foliation point to their being steeply inclined, in reality we are dealing with a thin series lying approximately horizontal, the different members of which are often repeated by folding. These sediments have, on the whole, suffered very little from those agencies of metamorphism which farther eastward have resulted in the destruction of original structures and the production of normal crystalline schists. The metamorphism in this area has been of a comparatively mild type, and is not always uniform in character. Even in the most altered sediments the clastic nature of the rock is always apparent, for although the finer-grained grits have been crushed and granulitized, the larger grains have been merely flattened; while in the least altered zones they have practically escaped altogether—microscopic examination revealing no granulitization, and the beds are little removed in condition from normal Palæozoic sediments.

With these sediments is associated much igneous material belonging to the epidiorite-group, which is commonly distributed as sills in this part of the Western Highlands. As these rocks play so important a part in the crush-conglomerates it will be necessary to describe them a little more fully than the sediments, on account of their complex character, both in regard to composition



Loch Awe Series. Ardrishaig Series. Other Dalradian Schists not differ-entiated on this sketch-map. Volcanic rocks of Lorne: Lower Old Red Sandstone. Epidiorite and allied rocks. ✱... Crush-Conglomerate localities.

[The little inset-map of Creag-nam-Fitheach and the neighbouring area is enlarged to the scale of about 2 miles to the inch, in order to show the distribution of the crush-conglomerates thereabouts more clearly than is possible in the general map.]

and metamorphism. In this particular district, of which the crush-conglomerate area forms a part, the igneous rock so exceeds the sedimentary material that over a large tract of country it may be said to play the rôle of groundmass. A zone of this rock is continuous for a breadth of 5 miles, among which discontinuous strips of sediment are embedded, while fringing this big mass, the sills of epidiorite, though large and numerous, form discontinuous intrusions enclosed by sediments.

Although portions of this large mass, which extends from Kilmichael to Loch Awe, may be described as normal epidiorite, it embraces rocks of such totally different type that this term would be altogether misleading applied to such local variations. But as it includes much typical epidiorite, and as there is very little doubt of its being allied with other sills of like type in the district, it finds its place naturally within that group. It shares in the metamorphism of the sediments with which it is associated, and, like those deposits, it varies in the amount of alteration that it has undergone. The mass, which is sometimes vesicular, varies in composition from basic to intermediate. The dominant minerals are hornblende and plagioclase-felspar, with chlorite, epidote, calcite, quartz and iron-ores as the more important accessories. There is every gradation in structure, from a coarse gabbro-like type to the finest schist. It is sometimes very coarse, often foliated, consisting of hornblende and felspar, the hornblende occurring in platy crystals up to ½ inch in length, and the felspar in elongated prisms, while epidote is abundant. Zones of finer texture composed of hornblende and felspar also occur; in these the rock is massive and compact, and approaches a fine schistose diorite in character.

The most prevalent type is a felspar-hornblende-schist with porphyritic felspars scattered about in it. With this type bands of very fine chlorite-schist are commonly seen, in which the porphyritic felspars are equally abundant. Rapid alternations occur of zones in which the amount of porphyritic felspar varies, in some bands being altogether absent. Similarly, the groundmass of the rock varies both in texture and in composition. These differences of structure and composition are often so sharply pronounced that banding is produced in the rock. In the varieties where chlorite takes the place of hornblende the rock occurs as a green schist or slate which, when the porphyritic crystals of felspar are absent, cannot readily be distinguished in the field from a sediment.

The porphyritic felspars occur in idiomorphic crystals, but they are often broken across and their outlines sometimes rounded, yet notwithstanding the highly-sheared matrix they have, on the whole, suffered very little crushing. They frequently measure half an inch, and rarely 2 inches in length. In some zones they are so packed together to the exclusion of the groundmass that the latter is insignificantly represented. Although portions show the hornblende as porphyritic, this type is not common.

While as a whole the rock is fairly fresh, both in the coarse dioritic varieties and in the fine chlorite-schists, considerable masses are

nevertheless met with in a highly decomposed condition, in which the hornblende has completely broken down; but tiny felspars often remain. When these latter are absent the igneous character of the rock is obliterated. In this condition the rock becomes very calcareous, arising from the breaking down of the lime-bearing hornblendes and felspars, and partly, doubtless, from the decomposition of the big limestone-masses with which these rocks are associated. That these green calcareous schists are the products of the alteration of the epidiorite there is abundant evidence to show. Cores of epidiorite of various types may be followed from their normal fresh condition, passing gradually outward into these nondescript green calcareous schists. When rocks of this type are interfolded with sediments, it is often a matter of extreme difficulty to separate them from very similar calcareous beds of sedimentary origin. In some cases boulders derived from this material have been looked upon as sedimentary, which has led to the crush-conglomerate being mistaken for the Boulder-bed.

Epidote is commonly distributed throughout the epidiorite-mass as grains in the rock, or in a more massive condition in cores, veins, and strings, intermixed with quartz, and forming epidosite. Cores of epidosite, from a few inches to a foot or more in their longest diameter, pervade all the varieties of the rock, and in the calcareous chlorite-schists are often the sole remaining link which connects them with the unaltered epidiorite.

The intimate nature of the interfolding will be apparent from the following illustration. The country bordering Inverliver on Loch Awe perhaps comprises the least altered rocks of the district, both igneous and sedimentary. Here grits and slates may frequently be seen quite unaltered, having suffered very little from the effects of crushing. The big igneous sill presents a similar condition, the porphyritic felspars of idiomorphic character have generally suffered little or no alteration, and the rock has none of the characteristics of an epidiorite, but preserves structures which are truly igneous, and appears in the field as bands of more or less altered andesites or andesitic dolerites divided by bands which are more sheared. In the section, for instance, at Eilean Liver, bands rich in porphyritic crystals of idiomorphic felspar alternate with layers of chlorite-schist in which the porphyritic felspars are absent. With these compact bands are alternations of the same material but very vesicular, some of the vesicles being filled with quartz and others with calcite, while some cavities are empty, and occasionally we see thin strips of limestone. The whole has a very bedded appearance, with the respective bands of alternating material dipping at a high angle and averaging about a foot in thickness.

Numerous sections along the northern coast of Loch Awe may be observed, presenting similar characters. Near Arichamish, however, about 1 mile east of Inverliver, igneous rocks of this character are seen divided by a band of grit, and instead of a normal junction between the two rocks the line of demarcation is represented by a complex of minute folding, strips of fine grit

alternating repeatedly with strips of igneous material thickly studded with porphyritic felspars. The bands of alternation, both sedimentary and igneous, range from an inch to a foot in thickness. That the banding is due to repetition by folding can be readily seen by the 'nosing-out' of the folds, though the section presents an appearance of perfect regularity, with the dip highly inclined. This composite zone of plication extends for a few yards, and there are other localities where similar composite outcrops spread considerably farther. In this case we are dealing with sedimentary and igneous materials of so unaltered a type that no question arises as to their character, and it is solely due to the fact that the banding occurs in rocks so fundamentally different that the phenomenon can be detected.

With such examples therefore in the district, showing how minutely the rocks may be interfolded while at the same time retaining an evenly-bedded appearance, the apparent magnitude of the banded igneous material must be received with caution. In describing the section at Eilean Liver it was noted that thin strips of limestone occurred among the banded igneous rock. The nearest limestone sufficiently large to be drawn on the 6-inch map is 400 yards distant, and it is probable that the strips of limestone are here interfolded and derived from a former extension of the limestone-outcrop, either above or below the present ground-surface.

Besides epidote, tiny crystals of albite, similar in appearance to the albites occurring among the mica-schists in Cowal, have been occasionally observed, both in the unaltered rock and its metamorphosed equivalent.

The mapping shows that the epidiorite-mass reposes indiscriminately on the different members of the Loch Awe Series, but its base appears to coincide in a general way with the horizon of the limestone. It has produced contact-metamorphism in the limestone, the black slates, and the quartzites. The fact of its resting indifferently on each member of the Loch Awe Series need not necessarily imply that it was not contemporaneous, as the sediments may pass laterally into one another, and there is evidence indeed that this is sometimes the case. Yet when the relations of the igneous to the sedimentary rocks are critically examined over the whole area it is impossible to resist the conclusion that the rock is intrusive.

While the occurrence of vesicles would at first sight suggest that we are dealing with a contemporaneous rather than an intrusive rock, yet when this evidence is carried further it tends rather to support the view that the rock is intrusive. Field-evidence shows that the vesicular varieties occur at the base of the mass, and although in such a folded area it cannot always be demonstrated that these types occupy this position, yet it can often be shown conclusively that such is the case. Of course, the possibility of a complete reversal of the sill by folding has to be taken into account. But while this may often happen to the smaller sills, it is hardly likely to do so in the case of a mass of such magnitude as this with which

we are dealing. My previous work in the district has demonstrated that, in spite of the dip being at a high angle, the members of the Loch Awe Series are lying nearly flat in a gentle trough of the Ardrishaig Series, and that, notwithstanding the great plication of the district, a general upward succession can be established.[1] When the stratigraphy of the area is considered it does not seem possible that an overfold so gigantic as to completely reverse the position of a mass having a breadth of outcrop of 5 miles could escape detection. Further, if such an overfold could be established, although it would place the vesicular varieties at the surface, fresh evidence would be encountered supporting the intrusive origin of the mass, for the contact-altered rocks have only been observed at the base of the mass, which by this process of reversal would be brought uppermost.

After reviewing the evidence at our disposal respecting the relations and character of this interesting rock-mass, there appears to be no sufficient reason for removing it from the great group of epidiorites and allied rocks of Dalradian age, the intrusive origin of which has been sufficiently demonstrated both in this and adjoining areas.[2] Moreover, the absence among the comparatively unaltered sediments of any trace of volcanic ashes or agglomerates lends further support to this conclusion, especially when it is borne in mind that the metamorphism in this area is never sufficiently potent to mask the original rock-character.

The smaller sills which occur among the sediments beyond the boundaries of the big mass call for no special comment, consisting as they do of types which find their equivalent within the mass described.

The igneous intrusions of post-Dalradian age being posterior to, and having no relation with, the crush-conglomerates, require no description in this paper.

III. Description of the Crush-Conglomerates.

It has been pointed out that folding of an isoclinal type is prevalent over the district, and that this type of folding has in some instances proceeded so far that the rock-sequence is now represented by a banded zone, in which the alternations are so narrow that they range from a foot to as little as an inch in thickness. While in some cases the process has ended here, in others it has been carried a stage farther, and the closely-packed folded bands have been divided by shear-planes severing the continuity of the limbs until lenticular fragments have been produced more or less isolated, culminating, by the rolling-out of the lenticles, in the production of p s e u d o - or c r u s h - c o n g l o m e r a t e s.

These structures have been observed in the limestones, the quartzites, and the epidiorites, but they are most conspicuously developed where the limestone and the epidiorite are in juxtaposition. Sections are but rarely seen in which the various processes

[1] See my former paper, Quart. Journ. Geol. Soc. vol. lv (1899) pp. 475–76.
[2] *Ibid.* pp. 476–78.

of crush-conglomerate manufacture can be continuously traced from the initial to the final stage, and consequently structures which have originated in earth-movements have, in some cases, been confounded with phases of contemporaneous deposit analogous to the Highland Boulder-bed.

As the principal physical features of the region correspond both with the strike of the beds and the axis of folding, deep transverse sections showing clearly the passage of one rock into another are far from plentiful. That part of the parish of Kilmartin, however, bordering the upper end of Loch Craignish, is divided by valleys which truncate the prevailing surface-features. We consequently find isolated platforms blocked out, so to speak, from the rest of the country, and as these transverse valleys owe their origin to faults, steep escarpments have resulted, displaying sections transverse to the strike and to the folding axes. The hill of Creag nam Fitheach, overlooking the head of Loch Craignish, forms one of these platforms, with precipitous slopes on its northern, western, and southern boundaries. The last-named, however, affords the best section, being almost a perpendicular escarpment and bare of vegetation. This truncated platform displays effectively the tectonic arrangement of the country adverted to earlier. While the folding and foliation are everywhere seen to be dipping at high angles and often perpendicular, the escarpment-faces show that the beds, although somewhat undulatory in behaviour, are generally horizontal, in fact, the exact converse of what the surface-features indicate. Examination shows a big mass of limestone interposed between epidiorites. The mapping suggests that both epidiorites form part of a single mass. The nature of the ground, however, does not permit of this being proved; and it must be admitted that the epidiorite which underlies the limestone is more crystalline and massive than that which rests upon it. So that, notwithstanding the variation shown earlier to exist in the epidiorites of the district, which might sufficiently account for its divergent character, there is just the possibility that we are dealing with two sills which partly overlap, although this supposition is unlikely. The upper igneous mass, with which we are particularly dealing, is of the vesicular type already noted. This epidiorite is a detached portion of the large complex sill that I have already described. Its junction with the limestone is intricately folded, and of as intimate a type of plication as that described earlier from Arichamish (pp. 318–19): folded limbs of epidiorite, from a few inches to a foot or more in thickness, being packed together at a high angle in a limestone-matrix. In the sections, big blocks may be seen in process of division by the shearing movements which have succeeded the folding. Among the folded limbs lenticles may be observed which have become completely isolated, consisting usually of epidiorite and sometimes of limestone. The limestone, however, seems generally to have played the part of a plastic body, and has accommodated itself as a matrix to the folded and isolated fragments of epidiorite, between which it has been squeezed. At the south-eastern corner of the hill

a bed of this nature, varying from 2 to 6 yards in thickness, rests upon the limestone more or less horizontally. In this bed the long edges of the folded limbs and detached fragments are in alignment with the strike of the foliation and of the folding axes of the district, so that we have, in cross-section, a series of closely-packed lenticles standing on edge, bound together by a limestone-matrix. The junction, however, of this composite mass with the limestone below is not sharp; blocks of igneous material are seen included in the limestone for some yards from the epidiorite-mass, some of which are well rounded, while near the top of the limestone, and below the composite bed, some solid blocks of epidiorite occur, 2 or 3 feet across, which have not been broken down into lenticles. On the north-western corner of the hill the limestone contains boulders of epidiorite, perfectly rounded, ranging in size from a foot downward, extending to some distance from the epidiorite-mass and considerably below it. An examination of these boulders shows that they belong to the vesicular type of epidiorite which reposes on the limestone, but most of them are considerably fresher and more compact, the fresh compact varieties showing no foliation. Boulders, however, do occur of the more decomposing type, which is the prevalent feature of the parent mass. There seems, on the whole, to be some grounds for assuming that the crush-conglomerates are anterior to the foliation, and that the boulders largely escaped deformation owing to the relative plasticity of the limestone-mass in which they are enclosed. Boulders of grit are also seen in the limestone, but these are evidently derived from a grit-band which is sometimes seen to abut against that mass.

Another example may be cited. On the steep scar-face, near Creagantairbh, a junction is seen of a massive epidiorite and a limestone, where the junction-rock for many yards is intimately interfolded, the folded bands ranging from 5 or 6 inches or more in width, down to tiny films. Some are more or less continuous, while others have been so far isolated that the rock simulates the appearance of a compressed Boulder-bed, with the fragments all steeply inclined and lying in one direction, but without having been rounded. The limestone is of the same coarse gritty type as at Creag nam Fitheach, and the igneous lenticles show clearly the small felspars. Another limestone-exposure adjoining, contains detached blocks and angular boulders of the epidiorite, while a little farther removed an isolated well-rounded boulder of epidiorite was seen in the limestone. Close to these exposures some thin strips of limestone occur, containing rounded inclusions of quartzite exceeding 1 inch in diameter, and boulders of the epidiorite which bound the limestone. These igneous boulders contain much calcite, and some dark crystals of the same mineral which is so common a characteristic of the limestone. They would therefore seem to have been embedded in the limestone before its final crystallization.

Many instances might be cited where similar structures have been set up near the junction of the limestone and the epidiorite, and apparently on the same stratigraphical horizon.

In the light of this evidence I revisited some of the sections in the immediate neighbourhood which I had formerly regarded as indicating contemporaneous erosion.

About half a mile north-north-east of Balameanoch an epidiorite and gritty limestone are seen in juxtaposition. The former rock on one side of the limestone is sufficiently fresh to leave no doubt of its igneous origin, crystals of hornblende and felspar being easily recognized, while on the other side of the limestone it occurs as a vesicular, green, calcareous chlorite-schist, much decomposed: a type of rock, as mentioned earlier (p. 318), into which these epidiorites often merge, and extremely difficult to distinguish from similar rocks of sedimentary origin. The limestone is conglomeratic, being studded with grains of quartz and felspar which sometimes attain 1 inch in length. In addition, however, we find numerous flattened boulders derived from the adjoining calcareous chlorite-schist. When the ground was mapped, the evidence furnished by these boulders led me to regard the deposit as one of contemporaneous erosion, and representative in this area of the Highland Boulder-bed. I was likewise led to consider the calcareous chlorite-schist as a sediment: for, being precluded by this interpretation from placing it with the epidiorite-sills, the only other alternative was to regard it as an altered lava or ash-bed, which the evidence over the district generally did not support.

On re-examining the ground last year it was apparent to me that it was a repetition of the sections of crush-conglomerate that are so readily formed at the junctions of the gritty limestone and epidiorites. A careful examination of the calcareous chlorite-schist failed to reveal the smallest trace of recognizable clastic material. Further, its homogeneous nature and the absence of any evidence of the alternations of the material of deposit, pointed to its forming a part of the big igneous sill of this district into which it appears naturally to pass.

Considering the comparative readiness with which this limestone lends itself to the manufacture of crush-conglomerates I am inclined to be doubtful in cases where this material has been regarded as forming the matrix of boulder-beds, whether we are not dealing with the former phenonemon. The time at my disposal in the Highlands last season did not admit of my re-examining those localities in the Loch Awe basin which I had instanced in my former paper[1] as furnishing examples of the Highland Boulder-bed, but provisionally it would be safer to regard those in which the matrix is calcareous as crush-conglomerates.

As stated earlier (p. 320), these phenomena, although most prevalent in the limestone and its junction with the epidiorite, are not confined thereto. Near Creagantairbh similar structures are observed in a band of fine quartzose rocks, which occupy a zone 5 or 6 feet in thickness between coarse massive grits. Some of the quartzose rock is very fine-grained and compact, having almost the appearance of

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 487–89.

hornstone. It has been folded, fractured, and the fragments isolated, the various stages of crush-conglomerate manufacture being so apparent as to leave no doubt that we are dealing with a process of mechanical deformation.

Similar structures have also been detected within the epidiorites themselves, although, owing to the comparatively homogeneous nature of the material, they are not so conspicuous, and consequently may easily escape observation. Fragments, however, of epidiorite may here and there be seen enclosed in the main mass, as well as the remains of crests and limbs of folds which have been torn from their original position and augen-structures set up.

Now that these phenomena are properly understood, other instances in which boulders have been found embedded in a matrix of material either similar to, or different from, the boulders can be explained. Isolated boulders of quartzite have often been observed in a matrix of the same material, likewise boulders of slate and of limestone have been met with enclosed in limestone. For want of a better explanation, they have been assumed to be related to the Highland Boulder-bed, but there can be very little doubt that in this part of Argyllshire they are more often crush-conglomerates, and that structures formerly supposed to be of sedimentary origin are in many instances products of mechanical deformation.

IV. General Remarks.

In discussing in the Summary of Progress of the Geological Survey for 1899 [1] the crush-conglomerates of Cornwall, stress was laid on the fact that the composite banded nature of the slates in which they occur played an important part in the manufacture of those structures: bands of alternating and divergent material offering a resistance to stress less uniform than would be the case with more or less homogeneous masses. In Argyllshire we find likewise that crush-conglomerates are most commonly produced near the junction of rocks totally dissimilar in character, the junction of epidiorite and limestone being especially favourable for their production. In this respect the fact that the limestone associated with these crush-conglomerates is generally of a gritty nature may be worth taking into consideration. It is often thickly strewn with grains of quartz and felspar, sometimes attaining even an inch in length, and it is possible that the composite nature of this rock has tended to favour differential movements within its mass, and rendered it easier to accommodate itself to the tendency to brecciation at the interfolding of its junction with the tougher epidiorites. In this rôle it seems to play so subordinate a part that, instead of contributing its own share of boulders to the crush-conglomerate, its plasticity has been such that it has been readily squeezed between the brecciated epidiorite, and forms the matrix in which these boulders lie. It is possible that a rock of more homogeneous composition would have offered sufficient resistance to prevent brecciation, and that instead

[1] See also Trans. Roy. Geol. Soc. Cornw. vol. xii, pt. vi (1901) p. 403.

of the formation of a crush-conglomerate merely a folded junction would have been produced, like that at Arichamish (pp. 318–19).

The study of these crush-conglomerates has also brought out the fact that not only are they largely confined to rocks similar in lithological character, but they also occur mainly at a definite horizon, which may to some extent account for their being regarded as of sedimentary origin. It will be readily understood that considerable difficulties may arise in determining whether such rocks owe their structures to original deposition or to mechanical deformation. Especially will this be the case when, as may easily happen, the rock which has given rise to these superinduced structures was itself originally a conglomerate. For instance, the gritty limestone at Creag nam Fitheach, although not coarse enough in its structure to be classed with a conglomerate, yet occasionally contains pebbles, probably original, which are as large as some of the smallest fragments formed by the crushing of the epidiorite. And it is evident that where the same mass exhibits structures, some of which are original and others superinduced, caution is required in any determination based on such evidence. In many instances great difficulties must arise in distinguishing structures which are depositional from those produced by deformation: the most valuable aid to such determination is the presence of foreign boulders. In cases, however, where the matrix of the crush-conglomerate is coarse, we may see pebbles of foreign material which are original and depositional, approaching in size the smaller boulders due to deformation; and in a crush-conglomerate of this type the presence of these pebbles might be construed as evidence that the whole deposit was a boulder-bed. Caution must be used, therefore, to make certain that the foreign boulders which are selected to decide the question approximate in size to the boulders the origin of which it is sought to determine.

In the same way the crush-conglomerate may contain boulders the source of which is not now visible in the immediate neighbourhood, and which would appear to favour therefore a depositional origin. But the evidence of the Eilean-Liver section, in which tiny strips of limestone are seen infolded with the big sill at a distance of nearly a quarter of a mile from the nearest visible limestone, demonstrates the fallacy of this reasoning. In so disturbed a region we must consider whether the parent mass had not such an underground or overhead extension, from which the crush-conglomerate boulders might have been derived. As an illustration, the crush-conglomerate of Creag nam Fitheach may again be cited. Let us suppose, for example, the top of this platform to be stripped by denudation of its surface-cap. The basement of the epidiorite and its junction with the limestone would then be removed, and we should see on the north-western flank of the hill a limestone enclosing well-rounded boulders of vesicular epidiorite having all the appearance of a boulder-bed, and the nearest visible source of supply for these boulders being now far removed from such deposit, its supposed depositional character would be strengthened.

Although in this particular case the composition of the enclosed boulders might create doubt as to their contemporaneous character, yet if the enclosed boulders happened to be sedimentary (quartzite, for instance, instead of epidiorite), the deformational character of the structure would never be suspected, and the deposit would be classed naturally among the boulder-beds.

These structures, both in Argyllshire and Cornwall, being evidently related to similar phenomena in the Isle of Man brought to light by the researches of Mr. G. W. Lamplugh, his designation of crush-conglomerate has been adopted for pseudo-conglomerates of this nature.

[Since Mr. Lamplugh's paper on the 'Crush-conglomerates of the Isle of Man' in 1895,[1] Messrs. Gardiner & Reynolds have described conglomerates of this nature at Portraine in County Dublin,[2] and it is interesting to note here that the crush-conglomerate which they describe has been brought about by the breaking-down of a limestone.

In the Annual Report of the Geological Survey for 1895 some remarkable examples of the pseudo-conglomeratic structure among the Lewisian gneiss were described in the ground mapped by Mr. Horne in the neighbourhood of Loch Alsh. There a deceptive resemblance to conglomerate has been produced by mechanical movements, and bands of chlorite and actinolite-schist enclose rounded and oval masses of biotite-gneiss and small blocks of quartz.

Forty years ago Mr. H. C. Salmon, in a paper read before this Society, referred to the fact that the occurrence of boulders and pebbles in the underground working of Cornish mines had long previously been recorded in the Transactions of the Royal Geological Society of Cornwall, and he quoted extracts from Messrs. Carne's and Henwood's papers. These brecciated rocks occur in a lithological division which I have shown to be very productive of these pseudo-structures. Although these subterranean sections are no longer available for inspection, we may confidently explain their occurrence as crush-conglomerates. Indeed, on the occasion of my reading a paper dealing with these Cornish structures at Penzance last November, Prof. Le Neve Foster reminded me of similar phenomena which had always remained a puzzle to the late Mr. W. J. Henwood, in whose company he had seen these underground sections.—June 12th, 1901.]

V. Conclusions.

The object of this paper has been to show that crush-conglomerates find their place in the Dalradian Schists of Scotland. I have also shown that they so simulate the appearance of sedimentary

[1] Quart. Journ. Geol. Soc. vol. li (1895) pp. 563–97.
[2] *Ibid.* vol. liii (1897) pp. 527, 531 *et seqq.*
[3] *Ibid.* vol. xvii. (1861) pp. 517–22.

deposits as to have been confounded with the Highland Boulder-bed. Moreover, this occurrence of both at the same general horizon may result in their appearance in the same section. In doubtful cases, the only safe test of original deposition is the presence of foreign fragments sufficiently large to escape being confounded with the materials which form the matrix. Similarly, the most satisfactory proof of deformational structure is the inclusion of igneous boulders derived from rocks posterior in age to the matrix.

I have shown that in this district the only Dalradian igneous rocks that occur are of intrusive origin, and that fragments of these enter into the material of the crush-conglomerates, fixing the origin of the latter beyond question. Owing to these phenomena not having been understood, igneous rocks in a decomposed condition have been considered as sedimentary. The junction of the epidiorites with limestone is especially favourable for the production of these pseudo-conglomerates. In this area the limestones of the crush-conglomerates are gritty, but this may be accidental, and normal limestones might have displayed equal plasticity.

These breccias were formed subsequent to the consolidation of the igneous rocks, as they only occur in association with those portions of the igneous masses that have undergone intense plication, of which they express the ultimate result.

The very nature of these structures tends to mask their identity: the more they approach in character the appearance of normal conglomerates, the more completely is their history obliterated. It is only a fortunate coincidence that has enabled me to demonstrate the origin of these crush-conglomerates of the Highlands by such an infallible test as that depending on the posterior age of their included boulders.

25. *On the* Occurrence *of* Silurian [?] Rocks *in* Forfarshire *and* Kincardineshire *along the* Eastern Border *of the* Highlands.[1]

By George Barrow, Esq., F.G.S. (Read May 22nd, 1901.)

Contents.

I. The Mode of Occurrence of the Rocks.

Along the south-eastern border of the Highlands, between Blairgowrie and Stonehaven, a remarkable group of rocks has been mapped in the course of the geological survey of that region. They occur as isolated lenticular strips, which intervene between the schistose rocks of the Highlands on the north-west and the boundary-fault that truncates the Old Red Sandstone on the south-east. The first and largest of these lenticular strips is about 20 miles long, extending almost from Cortachy in Forfarshire to about a mile beyond the Clattering Bridge in Kincardineshire. In the valley of the North Esk it is about ¾ mile broad, but elsewhere much narrower. The second lenticular mass begins at a point about a mile north of Drumtochty Castle, and stretches for 6 miles in a north-easterly direction to the Braes of Bervie. Part of a third strip is shown on the eastern margin of Sheet 66 of the 1-inch Geological Survey Map of Scotland, on the north side of the Highland Fault. The lenticular mode of occurrence of these rocks is due to the alternate approximation and recession of their northern margin from the great fault which everywhere forms their southern boundary.

II. Their Lithological Characters and Order of Succession.

Notwithstanding the mechanical deformation which these rocks have more or less undergone, we are still able to ascertain their original characters and mutual relations. They may be arranged in two divisions, namely:—(1) the Jasper and Green-Rock Series; and (2) the younger Margie Series.

Section in the North Esk River. (Fig. 1, p. 330.)

An almost complete section of the whole series is exposed in the North Esk, though parts are visible only when the river is low. Beginning at Gannochy Bridge, near Edzell, and proceeding northward, we traverse an almost continuous section of Old Red

[1] Communicated by permission of the Director of H.M. Geological Survey.

Conglomerate for about a mile, and thereafter the Lintrathen porphyrite. Immediately to the north of the latter igneous mass the rocks now to be described appear. The section is divisible into three parts.

The first and southernmost—about 400 yards long—is best seen when the river is low. The strata consist of sandstones or grits, reddish or pale brown on a weathered surface, but almost white in fresh fracture. Their milky-white aspect is due to the matrix being composed of carbonate of iron and lime, which effervesces briskly with acid. The pebbles in these grits may be seen by the eye, though at this locality they are rarely as big as peas. Some thin bands of white, grey, and chocolate-coloured shales are associated with these grits, which are sometimes cleaved. The characteristic feature of these shales, however, is the occurrence in them of original clastic micas, which serves to distinguish them from the Highland slates with which they were formerly grouped. Both shales and grits are seen to lie at all angles in the bed of the river, sometimes nearly vertical, sometimes almost horizontal. Local lines of shear or crush are frequently met with. Nevertheless a close examination of the section leads to the belief that the actual thickness of the strata is small.

At the northern end of this part of the section are two dykes of dolerite, probably of Tertiary age, and on the north side of the second dyke the curious pebbly limestone (Margie Limestone) was formerly noted by Lieut.-Col. Imrie. It is no longer visible, being now covered by river-gravel.

From the foregoing description it appears that the first part of the North Esk section exposes the members of the Margie Series, consisting of grits, shales, and a little band of pebbly limestone.

The second part of the North Esk section begins on the north side of the second dolerite-dyke just referred to, where a wall-like mass of rock crosses the river (see fig. 1, p. 330). The latter consists of a confused mass of jasper, calc-jasper, and Green Rock, which has obviously been subjected to intense dynamic action. The wall-like mass is followed by much deformed Green Rock, becoming more massive farther north, which, on examination, is found to be a crushed and decomposed basic igneous rock. Northward some thin bands of brittle red jasper are infolded with the igneous rock, and still farther up stream there is a considerable mass of jasper. On the sides of the rocky gorge the observer may note that the rocks are isoclinally folded, the limbs of the folds being nearly vertical; and it may further be seen that the increased thickness of the jasper is mainly due to repetition by folding. Moreover, the mode of occurrence of the jasper in the folds of the Green Rock shows that it is stratigraphically above that rock. Northward, some phyllite occurs, which, from the evidence in the gorge, is stratigraphically above the jasper. At the bend of the river, at the northern end of the Wood of the Burn, some interesting rocks appear, which will be described in the forthcoming Geological

Fig. 1.—*Diagrammatic Section about the North Esk.* (*See Geol. Surv. 1-inch Map, Sheet 66.*)

Survey memoir on that district. Beyond the bend for 250 yards, the river flows over Green Rock with numerous small vertical infolds of jasper.

The dominant member of the series displayed in the second or central part of the North Esk section is a more or less crushed basic igneous rock, to which the name Green Rock has been applied, owing to the persistent green colour produced by deformation. Jasper and jaspery phyllite are so constantly associated with these igneous rocks that the name Jasper and Green-Rock Series seems appropriate. It may here be noted that neither in the North Esk section, nor at any other locality in that region, is the base of this series visible; indeed, there can be little doubt that denudation has exposed only the top of what may possibly be a complicated series of igneous rocks.

The third part of the section in the North Esk begins at a point about 250 yards above the sharp bend already mentioned. Immediately to the north of the Green Rock is a coarse green conglomerate, made up of the underlying igneous materials, together with numerous small fragments of red jasper. The conglomerate is traversed by small planes of movement, and a more persistent movement-plane occurs at its base, where calcareous material has accumulated. The upward succession can be studied only when the river is low. Next in order comes a green grit, which heralds the beginning of the Margie Grits. As we ascend in the series the pebbles in these grits become smaller and the proportion of cementing-material becomes

greater, till a fairly thick band of shale is reached, which is followed by chocolate-coloured and dark-grey shale, the latter containing some carbonaceous material. Northward appears the band of pebbly limestone, which was formerly quarried here. A small band of dark shale runs through the quarry, being the highest visible member of the Margie Series in this section. Still farther north the limestone is repeated by folding, with a persistent dip to the north-west; but the strata are there inverted, for the shale-bands reappear, though in reverse order. Here the third part of this interesting section ends, for the shales are in conjunction with the slates of the Highland Series.

The many excellent sections north-east of the North Esk add little to our knowledge of the succession of these rocks. Moreover, with one notable exception, no fossils have been found in them, and it therefore became necessary to determine accurately their lithological characters, a summary of which is now given.

The Margie Series.

A characteristic feature of the whole group is the presence, often in considerable quantity, of white and brown clastic mica. Where the grits are much crushed there is some difficulty in recognizing them. The occurrence of these micas is, however, of importance, as they serve to distinguish the cleaved Margie Shale from the Highland Slate, in which, so far as this district is concerned, no such micas have been detected.

The pebbles in the grits consist of quartz and felspar, the former predominating. The felspar-pebbles consist almost entirely of oligoclase; this, where the rock is not decomposed, possesses the remarkable freshness that is known to characterize the oligoclase of the metamorphic series. This felspar abounds in the adjacent Highland rocks, and probably has been derived from them. The quartz-pebbles may have been obtained from the quartz-segregations so abundant in the Highland Schists.

As already indicated, the green conglomerate at the base of the Margie Series is composed of the detritus of the green igneous rock (Jasper and Green-Rock Series) and contains abundant pebbles, indeed, in places, boulders of that rock. Fragments of jasper are met with in the outcrop in the North Esk, but not in the exposure in the Kirkton Burn, about a mile to the north-east. Some of the larger boulders so closely resemble the basic lamprophyres met with in the Highlands that it was supposed they might be derived from that source; but more recent investigation has shown that a similar rock occurs among the Green Rocks, though this special type is not known in the North Esk district. The origin and local character of the green conglomerate is obvious, and attention has been drawn to the probable local origin of the pebbles in the grits. The carbonate-cement in the grits is probably also of local origin, for it may have been derived from the lime and iron set free by the decomposition of the basic igneous rocks (the Green Rocks).

The Jasper and Green-Rock Series.

The highest known member of this series consists of rather fine-grained sandstones, which, in a little stream near Brawliemuir, are infolded with the originally underlying shale. They differ from the Margie Grits, owing to the abundance of microcline in some parts of them, which has not yet been detected in these grits. Microcline is very rare in the Highland rocks near this locality, so that these sandstones have probably had a less local origin than the Margie Grits. This conclusion is strengthened by the nature of the underlying grey slaty shale, which has always a deceptively crystalline aspect. Thin microscopic sections of the latter rock show that it is less crystalline than many shales of the Coal-Measures: its finely crystalline aspect is due to the fact that it is built up mainly of minute clastic micas, embedded in a matrix of decomposed micaceous material, in which movement would take place with great facility. The clastic micas are so extremely small as to make it certain that the materials were laid down on the sea-floor near the edge of the zone of sedimentation, or on an area where deposition proceeded with extreme slowness.

The probable deep-water origin of this grey shale is confirmed by the fact that it overlies a bed of jasper, in which my colleague Mr. Peach detected circular bodies resembling the radiolaria in the cherts of the Southern Uplands. Only at one place, however, have radiolaria been detected in the jaspery chert, notwithstanding its great development in this region. Though the jasper is rarely sheared, it is usually much shattered, the lines of fracture being filled with quartz, which is always more coarsely crystalline than that in the jasper, and it is usually free from the iron-oxide to which the colour of the jasper is due. In places the jasper passes upward into a jaspery phyllite with a lower silica-percentage, and occasionally this phyllite appears to replace the jasper. Being softer, the phyllite is almost always sheared. In a few instances, however, even the jasper is 'milled,' as in the little stream near Brawliemuir. Though the red jasper is the type commonly met with in these areas, patches of green chert appear about the North Esk, where they are seen to be part of one and the same set of cherts, the difference in colour being due to the comparative absence of iron-oxide.

In several cases the silica-percentage of these cherts and jaspers has been ascertained, the results being given below:—

$SiO_2 = 88{\cdot}85$. Typical red jasper, North Esk; the most abundant type.
$SiO_2 = 71{\cdot}50$. Jaspery phyllite, North Esk; fairly abundant in many localities.
$SiO_2 = 93{\cdot}30$. Pale jasper, finely milled, Burn of Brawliemuir; milling exceptional.
$SiO_2 = 93{\cdot}85$. Mullion Island chert; rarely if ever sheared. (Quoted for comparison.)

The mode of occurrence of this jasper leaves no doubt as to its sedimentary origin; but the evidence that it was originally a radio-

larian ooze is by no means so satisfactory as one could wish. Still, if we compare the hand-specimens and microscopic sections with those of the cherts from the Southern Uplands, where the latter are somewhat altered, little doubt can be entertained that the cherts in these widely-separated regions had a common origin.

As already indicated, the term Green Rock is applied to a variable series of basic igneous rocks, usually green, a coloration due to the presence of a green mineral, which is often chlorite. In many places, however, it is a more or less distinctly green material, generally isotropic, which may be conveniently named viridite. The rocks vary considerably in texture, and to a less extent in mineralogical composition, and, with one local exception, the variation in ultimate chemical composition is small. The most abundant rock is an ophitic dolerite, in which the original basic mineral was augite. Indeed this type differs from the central part of a broad dolerite-dyke of Tertiary age solely in the fact that the latter contains more iron-ore than the Green Rock. The variation in the coarser varieties consists mainly in the partial replacement of augite by original brown hornblende and brown mica. This change is often accompanied by a slight difference in structure, the type containing these two minerals being not so markedly ophitic.

The coarseness of texture suggests that these rocks are probably intrusive. Indeed, in many cases it is clear that the igneous rock becomes more fine-grained at its point of junction with the jasper; but there is still a considerable residuum of fine material too decomposed to enable us to say confidently that it is only the quickly-cooled edge of an intrusion, and not part of a lava-flow. The junction-line with the jasper is often incrushed, and notwithstanding decomposition, it is evident that the upper surface of the igneous mass was not originally slaggy or uneven. The jasper has not been found filling cracks or fissures in the igneous rocks, as recorded in the case of the radiolarian chert in the Southern Uplands.

In several localities curious augen-shaped cavities in these basic rocks have been observed, suggestive of a coarse vesicular structure. These are so numerous at one locality near Brawliemuir, that a specimen showing one of these cavities was sliced in order to ascertain its character. This section (5570) showed that the hollow was formed at the intersection of two crush-planes, where the lime set free by crushing had been accumulated, and this being dissolved out afterwards, a cavity has been left.

Close to the locality just mentioned some pale-green and white igneous rocks are met with, which contain much more felspar than the normal Green Rock, and seem to have possessed an original flow-structure. They are more suggestive of a lava-flow, but they are so crushed and decomposed that it is impossible to determine precisely their original characters.

The Green Rocks, as a whole, seem to consist of a series of sills of ophitic dolerite, varying slightly in mineral composition and structure, and rarely continuous for any great distance. The fine-grained material is probably the quickly-cooled edge of these sills

repeated by rapid folding, though it is quite possible that some true basic lavas may also be present. The crushed and decomposed acid rock near Brawliemuir may, as already suggested, have been originally a lava. It must, however, be borne in mind that, owing largely to repetition by folding, no rock much below the horizon of the jasper is ever exposed.

The succession of the rocks in these lenticular patches that intervene locally between the Highland Schists and the Old Red Sandstone is tabulated below in descending order:—

Margie Series.

1. Grey shale.
2. Pebbly limestone, lenticular, 1 to 5 (?) feet thick; quarried at all known outcrops.
3. Dark carbonaceous, grey, chocolate-coloured, and white shales; about 20 feet thick.
4. Pebbly grits, with carbonate-of-iron cement, becoming coarser towards the base; about 120 feet thick in the North Esk section.
5. Green conglomerate, occurring locally about 30 feet thick in the North Esk section.

Jasper and Green-Rock Series.

1. Fine grit with microcline-pebbles.
2. Fine shale, always cleaved, with a pseudocrystalline aspect.
3. Jasper (altered radiolarian chert?), 6 feet thick in the North Esk section; at certain localities it seems to be replaced by jaspery phyllite.
4. Green Rocks, mainly lenticular sills of ophitic dolerite, though some lava-flows may also be present; upper part only visible.

III. The Age of the Two Series.

Attention has already been drawn to the local character of the deposits forming the Margie Series. The nature of the chert and fine shale associated with it points on the other hand to oceanic conditions of sedimentation, and suggests a wide distribution.

When I had completed the survey of the North Esk region, a series of uncrushed specimens and a section showing the geological structure of the area were examined by Mr. Peach, who at once recognized the resemblance of the Jasper and Green-Rock Series to the radiolarian cherts and volcanic rocks of Arenig age in the Southern Uplands, and the similarity of the geological relations in the two regions. Subsequently, most of the sections in the North Esk region were visited by Mr. Horne, who was equally impressed with the resemblance in the field, notwithstanding the deformation of the rocks along the Highland Border.

At a later date Mr. Peach and Mr. Horne showed me certain typical sections of the radiolarian chert and Arenig igneous rocks in the neighbourhood of Sanquhar, where the junction between the two is of two distinct types. In the first, the chert rests on an uneven surface of the pillowy lava, cracks and fissures in the latter being filled by chert: no similar junction has yet been detected along that portion of the Highland Border which I have examined. In the second type, the junction of the chert and igneous rock is perfectly even, and resembles that seen in the northern area of Forfarshire and Kincardineshire. In the latter region, the mechanical deformation which

the rocks have undergone gives them the appearance of an older series; but notwithstanding this fact, there is strong presumptive evidence that the cherts and green igneous rocks in the Southern Uplands and along the Highland Border are of the same age (Arenig).

Attention must now be directed to the question of the age of the Margie Series. The green conglomerate, as already indicated (pp. 330, 331), proves conclusively that these sediments are younger than the Jasper and Green-Rock Series. On the other hand, it is beyond doubt that the Old Red Conglomerate has not shared in the powerful movements that affected the Margie Grits. The relative age of the two is, however, placed beyond dispute by the fact that, in the area south-west of the North Esk, the Old Red Conglomerate passes unconformably over the upturned edges of the Margie Grits. The latter are, therefore, presumably of Silurian [?] age, though younger than Arenig time.

IV. The Nature of the Northern Boundary of the Silurian [?] Rocks.

Having established the order of succession of these rocks, and determined their age as far as possible, we will now consider their relation to the Highland Series.

Between the Highland rocks on the one hand, and the Jasper and Green Rocks on the other, are several small lenticular patches of the Margie Series which are shown on the Geological Survey Map (Sheet 66) and lettered *b*. These are five in number, and occur at the following localities:—(1) North Esk; (2) Kirkton; (3) Crichie Burn; (4) Clattering Bridge Quarry; and (5) Burnieshaig Quarry, north of Drumtochty Castle. The phenomena observed on the margins of these patches are so important as to justify me in entering into the following details:—

(1) The North Esk.—On referring to the description already given (p. 331) of the northern outcrop of the Margie Series in this section, it will be seen that there is a marked inversion of the strata near their northern limit. On the northern face of the old quarry the Margie Limestone, dark shale, and chocolate-coloured shale are repeated in reverse order with a north-westerly dip (see fig. 1, p. 330). It is clear that the beds north of the quarry are arranged in descending order, although from the apparent dip we might at first conclude that there is an ascending sequence. It is further evident that there can be no natural sequence between the chocolate-coloured shale at the northern limit of the Margie Series and the Highland Slate a few yards to the north, for no representative of the Margie Grits occurs here. And as there is no ordinary fault-rock present, it is most probable, in view of the great deformation of the strata, that the junction is a thrust-plane. But even supposing that this inversion could not be proved, the lithological evidence would demonstrate the fact that there is no true upward succession from the sheared Margie Shale, with its

original clastic micas, to the finely crystalline slate in which no trace of clastic mica has been found anywhere in this district. Briefly, it may be stated that at the junction of the Margie Series and Highland rocks we find the deceptive appearance of a stratigraphical sequence, accompanied by intense shearing of the softer rocks, so characteristic of the more important planes of overthrust in the North-western Highlands.

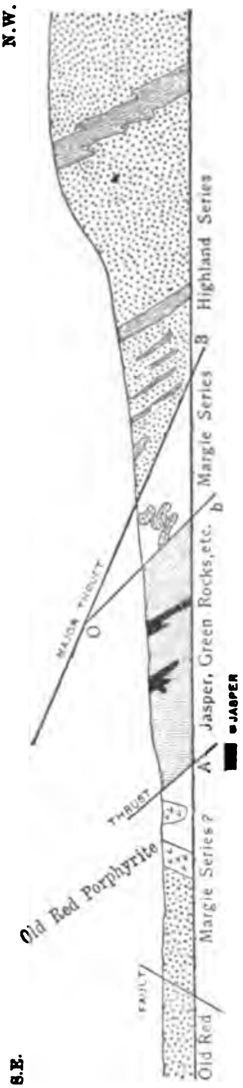


Fig. 2.—*Diagrammatic Section about Crichie Burn, Fasque.* (*See Geol. Surv. 1-inch Map, Sheet 66.*)

[The ground south-east of A is very obscure. In this and the following sections the lenticles of the Margie Series at the major thrust are enlarged, in order to make the details visible.]

(2) The Kirkton.—The sections about the Kirkton throw no light on the nature of the junction of the Margie rocks with those of the Highlands, and their discussion may for the present be postponed.

(3) Crichie Burn, north of Fasque (fig. 2).—In this small lenticle the limestone has been quarried on both sides of the burn. On the south side of the eastern quarry, the dark shales of the limestone are in contact with the grey slaty shale of the Jasper Series, and both are greatly deformed. From our knowledge of the succession, it is evident that the junction of these two rocks cannot be a natural one, and as there is no trace of normal faulting here, it is probable that a thrust-plane intervenes, the beds on each side of it being intensely sheared. On the north side of the quarry, the beds are apparently inverted as in the North Esk; for, although the dip is northerly, the strata are arranged in descending order as follows:—

1. Limestone.
2. Dark shale.
3. Chocolate-coloured shale.
4. Fine Margie Grits.

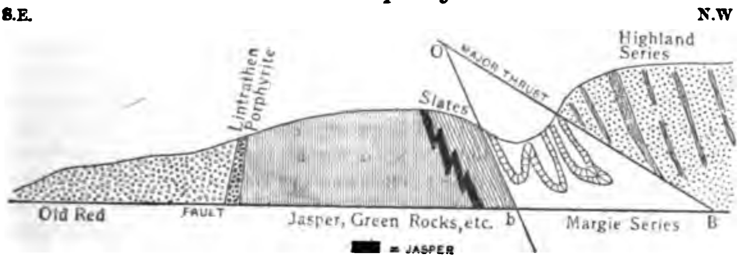
These grits form the lower part of a small waterfall north of the quarry, where their whiteness is well marked, but it disappears about a yard above the fall. Here the grit is clearly seen to be part of the Highland Series, and it is further apparent that the sequence cannot be normal, for the

lower part of the Margie Grits is absent, and so too the whole of the underlying Jasper and Green-Rock Series. In view of the intense shearing of the rocks at the fall, it is probable that the Highland rocks are driven over the Margie Grits by means of a reversed fault.

Two points are especially well shown here. First, it is impossible to locate the exact junction of the two series; secondly, the crushing accompanying this movement extends only for a yard or two into the Highland Grits.

(4) The Clattering Bridge Quarry (fig. 3).—Regarding the section in this quarry, it may be sufficient to state that, as in the Crichie Burn, the upper beds of the Margie Series are in contact with the Highland Series on the north side, and with the slaty shale and jasper on the south. Neither can be a natural junction, and there is no ordinary fault-rock present. The junction in both cases is marked by intense shearing, and both are probably thrust-planes. But we here see clearly for the first time that these two planes intersect at the top of the western end of the quarry, and that the more northerly plane cuts out the more southerly. The displacement along the margin of the Highland Series has been

Fig. 3.—*Diagrammatic Section across the Clattering Bridge limestone-quarry.*



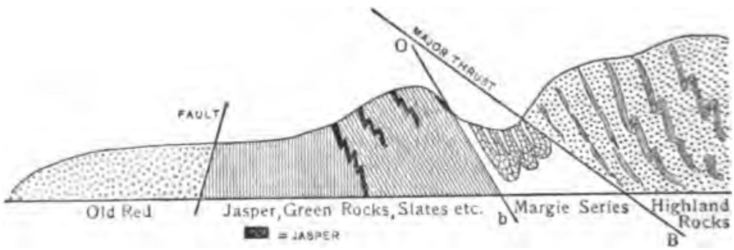
produced by a major thrust, and that between the Margie Series and the Jasper, etc., by a minor thrust. The effect of the intersection of these two thrust-planes is that, on the slightly higher ground to the south-west, there is no outcrop of the Margie Series. It is only because the burn here has cut through the point of intersection of the two thrusts, that the wedge-shaped mass of the Margie Series contained between them is exposed. This is made perfectly clear in fig. 3, above. Further, we now begin to see the meaning of the fact that these quarries all lie in valleys; for in the valleys alone has denudation cut deep enough to expose the rocks between the two thrust-planes.

(5) The Burnieshaig Quarry (fig. 4, p. 338).—This old quarry, in the Margie Limestone, lies about a mile almost due north of Drumtochty Castle, and a small burn flows through it.

Here the limestone has been exposed by the denuding action of the burn, and is not seen on the higher ground above in the line of strike. The Margie Series forms the floor of the quarry, and the beds are intensely puckered or folded, though careful examination shows that the folds are of no great depth. The peculiarity of this quarry is, that we are able to make out that at the junctions of the different rock-groups the section varies every foot. This is essentially due to a slight south-westerly inclination of the folding, in consequence of which we slowly ascend in the Margie Series as we walk along the floor in the direction of the strike of the folding. The southern wall of the quarry consists of the slaty shale, with the addition of small patches of intensely sheared jasper.

Fig. 4.—*Diagrammatic Section across the Burnieshaig limestone-quarry.*

S.E. N.W



This additional variation in the rock next the Margie Series makes the hypothesis of a natural sequence still more improbable. No fault-rock is present, but the shearing at the junction of the two series is intense. Similar phenomena are seen at the northern face of the quarry, where first the shale and then the limestone are in contact with a Highland Grit. The intersection of the two thrusts can be clearly made out at both ends of the quarry, and the cause of the non-appearance of the Margie Series higher up along the hillside, in the direction of the strike, can be easily understood. As already stated (p. 337), the type of crushing associated with these thrust-planes does not extend for more than a yard or two into the Highland Grit.

Thus these little lenticles of the Margie Series, on the north side of the Jasper and Green Rock, lie between a major and a minor thrust-plane. They are confined to the valleys, where alone denudation has succeeded in cutting deep enough to expose their apex. Only in the specially-deep valley of the North Esk is the whole succession of the Margie Series up to the limestone exposed. All along the hill-sides the minor thrust is always cut out by the major, before the former can reach the surface.

The Major Thrust.

The junction of the Highland Rocks with the Jasper and Green-Rock Series along the hillsides is more or less buried under Drift and other materials throughout the whole of the largest patch of the Silurian [?] rocks. But in the second, the evidence is fortunately more satisfactory. Between the limestone-quarry last described and the Bervie Water the course of the major thrust can, as a rule, be accurately traced. That the slaty shale, the jaspers, and the Green Rock are successively truncated by it as shown on the 1-inch Geological Survey map, is especially clear; for in several cases these bands can be followed to within a few feet of the Highland Grit, which can be traced persistently along the north side of the thrust.

In fig. 5 (p. 340) a reduced copy of a portion of the 6-inch field-map is given, in order to make this point perfectly clear: in no case is any fault-rock seen. It becomes obvious, therefore, that this major thrust is of great structural importance, and everywhere separates the great mass of crystalline (Highland) rocks to the north from the supposed Silurian rocks to the south, over which the crystalline rocks have been driven.

The Second Minor Thrust.

The junction of the southern outcrop of the Margie Series in the North Esk with the Jasper and Green-Rock Series is marked by a zone of intense shearing, described on p. 329 as a wall-like mass composed of lenticles.

In view of the evidence already given, this line of junction must also be a thrust-plane, for there is no ordinary fault-rock present, and the phenomena are totally unlike those of ordinary faulting. Though more important than the minor thrust-plane already described (see p. 337), it must also be a minor thrust, as it undoubtedly disappears on reaching the major thrust. Unfortunately, the exact place where the intersection takes place cannot be accurately fixed, for the ground is covered with thick Drift, as already stated.

V. The Position of the Major Thrust with reference to the Highland Rocks.

As I have already stated (p. 335), in the area a little to the south-west of that here described, the Old Red Conglomerate rests horizontally upon the upturned edges of the sheared Margie Grits, and is totally unaffected by the movements that produced the shearing. But the conglomerate itself is in turn affected by the great Highland Fault, which throws that rock down to the south in some cases for several thousand feet. Now viewed on a fairly large scale, the position of these two great movements, though of totally different ages, is almost identical, and there must be some cause for this approximate identity of position. This position we believe to be fixed by the condition of the Highland rocks. It has been found that

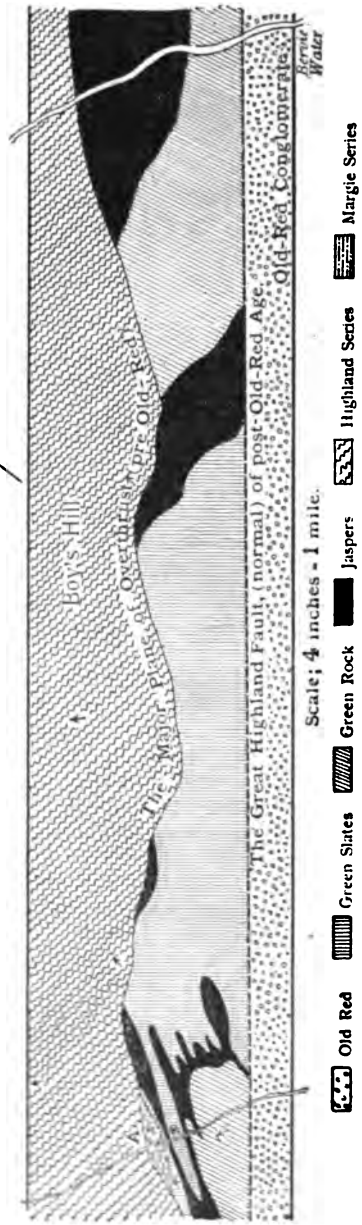


Fig. 5.—*Reduced copy of a portion of the 6-inch Geological Survey Map, Sheet 16 S.W.^r (Kincardineshire), showing the outcrop of the major and minor thrusts.*

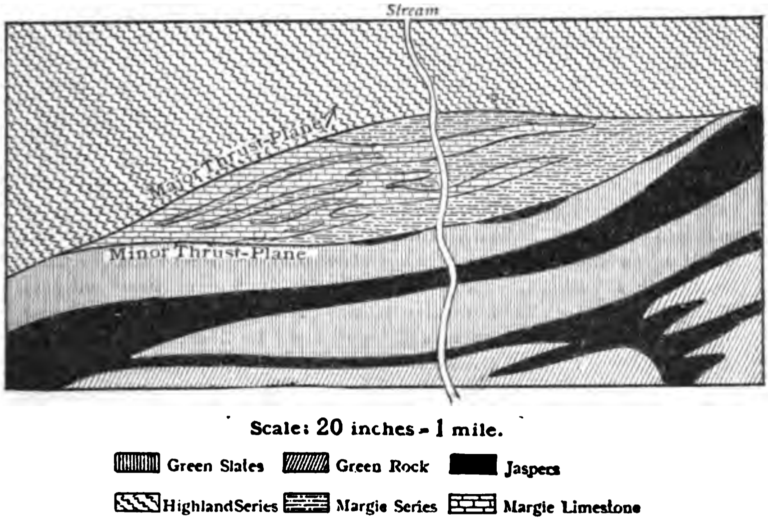
[In the above map is seen the contrast between the straight normal fault and the constantly curving overthrust.]

these rocks rapidly become less crystalline as we approach the position of these two great planes of disturbance. Close to these planes brown mica, of metamorphic origin, so abundant farther north, no longer occurs, and the only sign of alteration in the grits is the change in the clastic micas. Clearly if we could proceed a little farther in the direction of this decreasing crystallization, even this sign of alteration would be lost. The position, then, of the great planes of movement approximately coincides with the last trace of crystallization in the Highland rocks, which would be the position of least power of resistance to powerful earth-stresses coming from a south-easterly direction. Under the influence of such stresses the non-crystalline part of the Highland Series has snapped off from the crystalline and harder portion, and the latter has been forced over the

newer rocks composing the lenticles here described; just as the Lewisian gneiss has been forced over the Torridonian and Cambrian rocks in the North-western Highlands.

In the Southern Highland area, owing to the faintly marked crystalline character of the older rocks, an apparent order of succession has been produced that is far more deceptive than is usually the case in the Durness-Erribol area. Indeed, in the case of the North Esk section I was at first completely deceived by it, and it was only on mapping out the ground in minute detail that the deception was exposed.

Fig. 6.—*Enlargement of a portion of fig. 5, p. 340.*



[The complicated folding of the lenticle A of the Margie Series, seen in the former map (fig. 5, p. 340) between the major and minor thrusts, is well shown in the above enlargement.]

There is, moreover, another deception even more difficult to detect. Owing to the slightly crystalline condition of the Highland rocks we seem to see a perfectly gradual transition, through the greatly crushed newer rocks of these lenticles into the highly crystalline schists of the Southern Highlands. In reality, however, no such transition exists. Under the microscope the clastic micas can be recognized in nearly all the newer sedimentary rocks, even when close to the thrust-plane. No such clastic micas have ever been detected even in the least altered Highland rocks.

The facts and inferences set forth in the foregoing pages have a very important bearing on a matter of controversy. In the area here

discussed the rocks affected by what is commonly known as regional metamorphism have been driven over a newer series by a movement of pre-Old Red Sandstone age, and no similar movements have since taken place in this area. But on the margins of crystalline areas in other countries similar movements have taken place as late even as Tertiary times, and in such areas a Tertiary age has been claimed for the regional crystallization. In view of our experience both in the Northern and Southern Highlands, it seems not unreasonable to suggest that movements similar to those here described may have occurred along the slightly crystalline margin of the areas affected by regional metamorphism. Whatever may be the age of the beds overridden by the crystalline schistose rocks, there will appear to be a passage from the newer into the older, and the crystallization of both will seem to be somewhat later than the age of the beds so overridden. As in the case of the area here described, the transition from one series to the other may be deceptive.

VI. The Mechanical Deformation of the Silurian [?] Rocks.

I cannot conclude the account of the phenomena seen in these lenticles without some notice of their bearing on the vexed question of the origin of crystalline schists. Great as is the crushing and shearing in these lenticles, it has nowhere resulted in the production of a crystalline schist, and not a particle of new brown mica has been met with anywhere. The total length of outcrop of more or less basic igneous rock is about 10 miles. No hornblende-schist ever occurs in it. Indeed, it would be difficult to find an area which seems to show so conclusively that mechanical deformation alone does not produce crystalline schists. The structures in the sheared grits are in the main identical with those seen in the Torridon Sandstone of the North-western Highlands,[1] and in the Boulder-Conglomerate found by my colleague, Mr. G. W. Lamplugh, in the Isle of Man.[2]

VII. Summary of Results.

The results of the examination of the remarkable group of rocks described in this paper, which intervene between the Highland Schists and the Old Red Sandstone in Forfarshire and Kincardineshire, may be summarized as follows :—

(i) They may be arranged in two divisions—(*a*) the Jasper and Green-Rock Series, and (*b*) the Margie Series. The former is most probably of Arenig age, and the latter is of later date, though undoubtedly of pre-Old Red Sandstone age.

(ii) Both groups of rock have been much deformed, the shearing being most persistent along the junction of the Highland rocks with the northern margins of the supposed Silurian rocks.

[1] Quart. Journ. Geol. Soc. vol. xliv (1888) pp. 431 *et seqq.*

[2] *Ibid.* vol. li (1895) p. 563.

(iii) The appearance of an upward succession at this line of junction is always deceptive, the boundary being marked by a great line of displacement or overthrust which has been proved to extend for many miles.

(iv) The apparent passage from the non-crystalline newer rocks (Silurian?) into the Highland schistose series is equally deceptive.

(v) The crushing accompanying this thrust never extends more than a few yards into the Highland Series, owing to the induration of the rocks of that series by previous metamorphism.

(vi) The position of the major thrust truncating the so-called Silurian rocks on the north and that of the later great boundary-fault skirting the Old Red Sandstone have been determined by the outer limit of the great aureole of crystallization of which the South-eastern Highlands form a part. The harder crystalline schists to the north-west have snapped off, under the influence of enormous pressure, from the softer portions now covered by newer rocks to the south-east.

(vii) Though the rocks have been much sheared, they have not been changed into crystalline schists. In particular, the sheared basic igneous rocks are never altered to hornblende-schists.

Discussion.

Sir Archibald Geikie stated that he had had occasion to examine the Author's evidence with him on the ground, and had no hesitation in agreeing with the conclusion arrived at by Mr. Peach and Mr. Horne that the series of jaspers and igneous rocks wedged in along the Kincardineshire border of the Highlands, between the metamorphic rocks and the Old Red Sandstone, bear the closest resemblance to the Arenig Group of the Southern Uplands, and are in all probability of the same age. The Author, however, had detected in that region a younger group of strata (Margie), which may belong to some later part of the Silurian System. The Arenig Group had been detected at other places along the Highland Border: by Mr. Clough between the Tay and Loch Lomond, and more recently by Mr. Gunn in the Island of Arran. Though the speaker had gone over the ground with the Author, he had not been able to detect any section showing indications of such a thrust-plane as the mapping would appear to require. Nor in the tracts farther to the south-west had it been practicable to draw any hard-and-fast line, between the Arenig Group and the metamorphosed clastic rocks of the Highlands to the north of them. It is possible that, while a thrust-plane may be shown by the mapping to exist in Kincardineshire, there may be no such break in the tract between Callander and Loch Lomond. In Arran, too, it has been found impossible to trace a definite boundary between the Arenig Group and the contiguous schists.

The questions involved in this paper are of the utmost interest and importance, both as regards the structure and history of the

Scottish Highlands, and with reference to theoretical questions in tectonic geology and metamorphism. If anywhere the Arenig Group really shades off without a break into the Highland Schists, we are at once led to enquire how much of these schists must be of Palæozoic age. But even if we claim that the boundaries of the group are everywhere actual lines of dislocation, we have to admit that the thrust-planes and metamorphism which have affected it, and which cannot easily be separated from those of the general mass of the Highlands, must be at least of post-Arenig age. And in that case we are naturally driven to ask how far the tectonic arrangement and crystalline condition of the Highland rocks have been determined or modified by movements that must be assigned to some date between the period of the Arenig Group and that of the Lower Old Red Sandstone. Having had opportunities of studying the rocks on the ground with each of the members of the Survey—Mr. Gunn, Mr. Clough, and the Author of this paper—who had surveyed the several areas in which they are developed, Sir Archibald could bear witness to the patience and skill with which the mapping had been carried out. If perfect agreement had not been reached in the interpretation of the phenomena, this difference of opinion only served to indicate the difficulty of the problems and the diversity of form under which they present themselves in the various districts. The speaker was inclined to believe that the key to the solution of these problems was most likely to be found in the North of Ireland, where, in the County of Tyrone, rocks which, there could hardly be any doubt, are a continuation of the Silurian Series wedged in along the Scottish Highland Border, expand over a broad stretch of country, and have been laid open in many natural and artificial exposures. They include sedimentary rocks among which are cherts and jaspers like those of the Arenig Group, and also red shales and pale grits and limestones, which may represent the Author's Margie Series. But their most remarkable feature is the great development of their igneous masses, which comprise ellipsoidal lavas, fine tuffs, and coarse agglomerates, together with intrusive sheets and bosses. These rocks require to be carefully mapped in detail, and their boundaries with the Londonderry Schists on the one side, and the Palæozoic formations on the other, must be closely traced. This task will not only tend to clear up an obscure chapter in Irish geology, but may help to remove some of the difficulties which still stand in the way of a satisfactory interpretation of the geological history of the structure and metamorphism of the Highlands of Scotland.

Mr. Marr, being interested in the relationship of the schists of the Highlands to the Palæozoic sediments, wished to call attention to certain slates which the late Hugh Miller, in his 'Cruise of the *Betsy*' 7th ed. (1869), p. 257, stated, on the authority of Dr. Emslie, were graptolite-bearing. The late Prof. Nicholson had made a cursory examination of these slates, and judged that they distinctly possessed the characters of graptolite-bearing slates. He (the speaker) urged that these slates should be re-examined.

Prof. BONNEY expressed his sense of the value of the Author's paper, which was quite in accordance with the speaker's own experience. He had himself seen greenstones reduced to a condition apparently as fissile as some of those on the table, and the bringing together in apparent sequence and in a narrow zone of rocks differing much in age, reminded him of one or two cases in the Alps, where it was often extremely difficult to fix the exact position of a thrust-plane because of the crushing in its vicinity. This, he had observed, always produced very great effects near the junction of two rocks differing much in hardness. The crushing near a fault had often misled observers into supposing a transition to exist from crystalline schists into phyllites. The difficulty was caused by the fact that in the former the minerals were reduced in size, and there might also be a minute secondary development of mica; while in the latter much minute mica (supposing the rock argillaceous) was produced as a consequence of the pressure. So on the one side there was a 'levelling-down,' on the other a 'levelling-up,' which occasionally made the two rocks very like one another. He thought it highly probable that Palæozoic rocks would occur in lenticles in the Central Highlands—indeed he believed that the late Dr. Hicks had identified Torridon Sandstone. Mesozoic rocks occurred in that way in the Alps; and he was more sanguine than Sir Archibald Geikie that in such cases the newer rocks would be identified with certainty.

The PRESIDENT and Mr. R. D. OLDHAM also spoke, and the AUTHOR replied.

26. *On the* USE *of a* GEOLOGICAL DATUM. By BEEBY THOMPSON, Esq., F.G.S., F.C.S. (Read June 19th, 1901.)

[Abstract.]

A PROPER interpretation of geological phenomena frequently requires that allowance shall be made for differential earth-movements that have taken place since the period under consideration. Present differences of level in rocks of the same age may be due to actual differences in depth of the sea-floor on which they were deposited; but they may also be the result of subsequent differential earth-movements. The rock selected as a datum should combine as far as possible the following characteristics:—It should be thin, of considerable horizontal extension, having similarity in physical characters and palæontological contents over a large area, and situated as near as possible, in vertical sequence, to the reference-deposit. In Northamptonshire three formations meet these requirements—the Rhætic Beds, the Marlstone Rock-bed, and the Cornbrash. The Author applies the Marlstone Rock-bed as a datum to the study of the five chief deep explorations in Northamptonshire, with the following results:—While the old land-surface (below the Trias) now varies in height by more than 250 feet, the variation in thickness of the rocks between it and the Middle Lias only reaches $56\frac{1}{2}$ feet; and although the old land-surface is actually lowest where the Rhætic rocks have not been detected, when compared with the position of the Marlstone it is found to be the highest. The further application of the same method enables the Author to recognize Rhætic rocks at Northampton, to correct the record of the Kingsthorpe shaft, and to explain the presence of Triassic saline water in the Marlstone. A revised section of the Kingsthorpe shaft is given. Another point proved is that a general levelling-up process was going on just before the beginning of the Lower Liassic Period, and another at the close of the Middle Liassic Period.

DISCUSSION.

The Rev. J. F. BLAKE and Mr. W. WHITAKER spoke.

The AUTHOR, in reply to Mr. Blake, said that he certainly thought that the upper portion of the Marlstone Rock-bed was formed at approximately the same depth over a very large area extending from north-east to south-west. In directions at right angles to this he would expect it to vary in character considerably. He thought that the process illustrated in the paper might, with advantage, be applied to the Lias and Oolites in other localities.

27. *The* Geological Succession *and* Palæontology *of the* Beds *between the* Millstone Grit *and the* Limestone-Massif *at* Pendle Hill *and* their Equivalents *in* certain other Parts *of* Britain. By Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S., and John Allen Howe, Esq., B.Sc., F.G.S. (Read February 20th, 1901.)

[Plate XIV—Vertical Sections.]

Contents.

I. Introduction.

The following paper is an attempt to define the geographical extent, stratigraphical sequence, and palæontological horizon of the beds which lie between the top of the Mountain Limestone and the series of grits known as the Millstone Grits. We have taken as the type-section that on Pendle Hill (Lancashire), where these beds attain their maximum development; and as the term Pendleside Limestone has already been employed by the officers of the Geological Survey to designate the calcareous member of the group, we propose to extend the term to the whole group defined above and call it the Pendleside Group.

It will be observed that this term includes the 'shales-with-limestones' that rest on the Mountain Limestone of the Derbyshire and North Staffordshire area, to which the name 'Yoredale' has been frequently applied; but one of us has already demonstrated the fact that the Yoredale Series of Wensleydale is totally different from the Pendleside Group, and that the former is the equivalent of the upper part of the Carboniferous Limestone massif, both on palæontological and stratigraphical grounds.[1]

The present paper is divided into six sections: the first being a brief introduction; the second describing in some detail the various occurrences of the beds with their fossils; the third embodies a general account of the palæontology; the fourth is a sketch of the probable physical conditions of the period; the fifth describes some of the chemical and physical characters of the rocks; while the sixth deals with the petrology and micropalæontology. In the Appendices are tabulated the fossils of the Carboniferous Limestone Series and the Pendleside Group.

[1] W. Hind, Geol. Mag. 1897, p. 159.

The main portion of the paper naturally deals with the country immediately bordering the Pennine System, but it has been found expedient to mention certain outlying areas such as Poolvash (Isle of Man); Budle (Northumberland); Venn (Somerset); and County Dublin and Foyne's Island in Ireland, where Pendleside fossils are found; or such districts as the Calciferous Sandstone area of Fifeshire, in order to bring out the range and horizon of some of the fossils (see tables of isodietic lines, figs. 2 & 3, pp. 380 & 382).

The reef-knoll district of Cracoe and Thorpe, near Skipton, has also been referred to, because the limestone of these knolls has erroneously, as we believe, been recorded as Pendleside Limestone.

II. The Stratigraphical Succession.

Pendle Hill constitutes the western margin of the Burnley Coalfield, and extends as a long ridge in a north-easterly and south-westerly direction. The north-western flank of the hill forms an escarpment which rises to 1831 feet above sea-level, and is composed of a complete succession of the rocks between the Millstone Grit and the Carboniferous Limestone. An almost continuous section is to be seen in the various brooks which drain the north-western flank of the hill, not indeed complete in any single stream, but certain stream-sections are complementary to the others.

The stratigraphical sequence is roughly as follows:—Forming the summit of the hill is a thick bed of grit, called by the officers of the Geological Survey the Pendle Grit, and identified as the equivalent of the 'shale' or Farey's Grit in the Peak District of Derbyshire. It is usually a fine-grained rock, though with local variations, and contains felspar, mica, and large concretions which are characteristic of Farey's Grit in the Peak District. Below the Pendle Grit comes a succession of black shales with thin earthy limestones; these were called the Bolland Shales by John Phillips, who recognized the fact that they were the equivalents of the shales below Farey's Grit in Derbyshire. In the Bolland Shales, existing as a lenticular bed, is a mass of sandstones with shales, to which the name Lower Yoredale Grit has been applied. This bed is of very local character, and cannot be clearly traced for any distance. In this respect it resembles many other beds of the Millstone Grit Series, which repeatedly pass laterally into shales, suddenly thicken, or die out altogether. The Lower Yoredale or Pendleside Grit occupies a slight depression in the contour of the hill, and consists of bands of grit and shale. The last-named contain a fauna identical with the shales above and below this grit-bed.

Underlying the Pendleside Grit is a series of shales and mudstones, more sandy in the upper part and more calcareous in the lower, which separate it from the Pendleside Limestone. This series forms a particularly well-marked feature all along the north-western flank of the hill, and is well exposed in the several 'cloughs' or brook-courses. The name Pendleside Limestone might give rise to the impression that there was a single moderately thick bed of limestone; but this is not so, for with the exception of the upper

part of the series (where the beds of limestone are closer together and not separated by shales), the limestones are comparatively thin, and the shales between them nearly equal in mass to the calcareous beds. The Pendleside Limestone commences at the top with a bed of large 'bullions,' very hard and compact, breaking with a conchoidal fracture, and containing goniatites (*Glyphioceras reticulatum*) and fragments of other fossils. This is underlain by beds of hard, compact, grey limestone with small crinoid-stems, as well as *Productus scabriculus* and *Pr. semireticulatus.* This passes downward into darker hard limestones, which break with a subconchoidal fracture and weather into 'anvil-forms.' They frequently have small chert-bands, are finely and regularly stratified, and are often polished by the peaty water. Whole fossils are scarce. Some distance lower down, about the middle of the series, is a bed of yellowish crystalline limestone, weathering grey, and showing small broken fragments of shells and crinoids projecting from its surface; bands of chert which weather white occur in places.

Below the last-named beds the limestones are thinner, darker and more impure, and shales gradually assert themselves. The black shales immediately at the base contain few fossils—*Chonetes Laguessiana*, *Productus Cora*, *Prolecanites compressus*, and *Orthoceras* sp.

From the foot of the Pendleside Limestone the surface of the ground slopes gradually down to the point where the Carboniferous Limestone rises again somewhat abruptly in the Clitheroe anticline. This space is occupied by soft black shales, with a few bands of impure limestone in the lower part containing a sparse but typical fauna.

The officers of the Geological Survey calculate the thickness of the beds between the top of the massif of limestone and the base of the Pendleside Limestone as 2500 feet, but we are of opinion that this estimate is too high. There are two points from which satisfactory measurements may be taken:—(1) from the inlier of limestone south-east of Downham to the base of the Pendleside Limestone; and (2) from Warsaw End to Moorside. The first affords few sections on the actual line, but exposures north-east and south-west of it show that the beds are comparatively undisturbed, and it is obvious that the whole succession must be included between the points mentioned. The Survey section (Hor. Sec. Sheet 85) passes between the above two lines and strikes the Carboniferous Limestone too far west, and therefore adds considerably to the thickness of the shale. Our own estimate of the thickness of these shales is 1500 feet, assuming an average dip of 30°.

The contour of the massif of limestone is very irregular, and does not correspond with the strike of the shales. This fact is well seen in the brook south of Warsaw End House, where a bed of limestone with calcareous shales is observed striking for some distance north-east and south-west, parallel to the strike of the beds on Pendle Hill, but not in any way parallel to the line of the limestone-feature which forms a number of bays and promontories. The distance of this limestone-bed from the strike of the Carboniferous Limestone

north-north-west of Warsaw End House is probably 100 to 150 feet, as the bed dips at 30°+ . . . , and is the only gap in the succession at this part. On the whole, the dip is high near the limestone-massif and diminishes from 50° to 15° or less, rising again to 30° towards the hill: this is the normal dip of the Pendleside Limestone. At a spot 200 yards west of Warsaw End House some calcareous strongly-jointed shales are seen, dipping off the white limestone at 65°. These are of interest, as they contain *Prolecanites compressus*, *Brachymetopus* sp., *Zaphrentis* sp., *Phillipsia* sp., and *Orthoceras* sp.

Between Warsaw End and the Pendleside Limestone, sections in the shales may be seen along three brook-courses—the Rad Brook, running past Hookcliffe and Radbrook Farm towards Warsaw End House, and its tributaries from the north-east and south-east; that from the north-east, flowing through Riddingwood; and that from the south-east, coming from Moorside.

In the Riddingwood section the shales are rather contorted, but in the other two streams the following sequence may be taken as characteristic:—

	Feet.
Hard calcareous shales	6
Black shales	40
Shaly cement-stones	12
Fissile shales	6
Gap	12
Hard calcareous shales	6
Gap	20
Hard calcareous shales	1
Black shales inclining to be sandy	12

The lowest of these beds dip 40° south-south-eastward, and the upper in the same direction at 20°; unfortunately no fossils were obtained. Continuing up the Rad Brook the section is uninterrupted, with the exception of a small gap below Hookcliffe, and shows a series of clayey shales and cement-stones containing a few fossils, such as *Aviculopecten* and *Goniatites*. The beds becoming more calcareous, pass into the Pendleside Limestone a few yards above the farm.

The section exposed in the Worston Brook and along the stream which comes down from Angram Green is fairly complete. The shales cannot here be traced right on to the limestone-massif, but the lowest exposures can hardly be far above it, as the strike of the beds remains unaltered between Warsaw End House and the point where the Mearley Brook crosses the municipal boundary of Clitheroe 1 mile away. The section begins immediately east of Hall Foot House with black shales and thin limestones. One of the beds of fissile calcareous shale contains the following fossils:—

Aviculopecten papyraceus.
Ctenodonta lævirostris.
Solenomya costellata.
Bellerophon Urei.
Productus longispinus.
Discina nitida.
Discites subsulcatus.
Orthoceras Steinhaueri (?).
Ceratiocaris sp.

Then succeeds a series of black shales with thin limestones, mudstones, and cement-stones, up to the base of the Pendleside Limestone.

The following section is seen in the stream west of Pendleton Hall, where the road crosses the stream:—

	Feet.	Inches.
Thin limestone and shales	12	0
Yellowish nodular shales	15	0
Shales with limestones	12	0
Shale	1	0
Well-bedded limestone	6	0
Limestone	2	6
Hard clayey shale	1	6
Puce-coloured limestone with conchoidal fracture and one obscure fossil, *Dielasma (?)*	6	0
Shaly limestone, harder at the top	1	2
Grey shales	0	9
Hard dark-grey limestone, weathering yellow, becoming earthy at the top; no fossils	8	0

These beds dip at 15° south-south-eastward, and are about 570 feet below the limestone mapped as Pendleside Limestone. The section ends at the small bridge from the road to the farm, and higher up the stream the shales are obscured by Drift until the Pendleside Limestone is reached. South-west of this point the limestone-feature rapidly dwindles away, just as it does at the north-eastern end of the hill, the last exposure in this direction being the little quarry on the road beyond Lanehead, west of Ravensholme, where it has been quarried. Farther north-east, along the flanks of Pendle Hill, the series seems to lose its feature-making character and to die away into the shales and thin limestones.

On the opposite side of the synclinal trough of limestone east and south of Waddington Fell, the Pendleside Limestone is not well developed, but fragments which we obtained at the old quarry of New-a-Nook, south-west of the Moorcock Inn, Waddington Fell, appeared to be very similar in character and composition with those of the Pendleside Limestone.

The brooks and streams which flow south-south-eastward from Waddington, Easington, Grindleton, and Bradford Fells show a series of black limestones and shales. It is difficult to obtain anything like a continuous section in this district, as the beds are so contorted, and the strike is subject to rapid alterations in direction. Beds of limestone, varying from 6 inches to 15 feet in thickness, are seen with beds of shale, also of varying thickness, between them. Fossils are extremely rare, a single lamellibranch (*Ctenodonta lævirostris*), fragments of encrinites, and a coral only having been found by Mr. Lomas, who kindly examined the sections for us. Speaking of these limestones in the Geol. Surv. Memoir on the 'Geology of the Burnley Coalfield' 1875, p. 18, Mr. Tiddeman says:—

'The Lower Yoredale Grit being absent over a good part of this district, these

limestones lie on very much about the same horizon as the Pendleside Limestone; but owing to the great contortions to which they have been subjected . . . and the thick drift which conceals them in many places, it has not been found practicable to map them, and they have been massed with the Shales-and-Limestones.'

There can be little or no doubt that these beds are the real equivalents of the Pendleside Limestone, already much diminished in thickness.

Around the flanks of Longridge Fell, the Pendleside Group is seen to be fairly well developed, occupying its proper position in the sequence, although it does not form so well-marked a feature as on Pendle Hill. Speaking of this locality Phillips says that no limestones appear 'so near to the Gritstone' as in Pendle Hill,[1] but several sections occur which show that the Pendleside Group undoubtedly exists there in fair strength. Two exposures occur on the farms occupied by Mr. Henry Mercer, which were once worked as quarries. Here well-bedded dark limestones are seen, with bands of shale. An extensive section is exposed in a quarry, now at work immediately north of the Longridge and Clitheroe road, three-quarters of a mile east of Thornley Hall. The beds were originally seen in a small stream, and later a quarry was opened. The beds here are much disturbed, but show a considerable thickness of thinly-bedded limestones, with shaly partings which become thicker and more frequent near the top of the series, and the upper beds of limestone exhibit well-marked strings and nodules of chert. Some of the characteristic fossils have been obtained here. Viewing the beds from the road above the exposure it was seen that they formed a definite feature, running parallel to the grits of Longridge. The explanation of Phillips's remarks is doubtless to be found in the more gentle slope of the Longridge Grits.

The Longridge section is completed by the exposure of the limestones and shales in the beck south and west of Thornley Hall, and the mass of limestone which is exposed along the axis of the syncline for some 2 miles, about midway between Chipping and Longridge Fell. This mass has been extensively quarried, and the beds are seen to dip north-westward and south-eastward. The section exposed in the quarry is very similar to those seen near Barnoldswick, and in the railway-cutting 1 mile north of Rimmington. The fossil *Palæechinus sphæricus* is common in both localities, and beds crammed with large crinoid-joints form a marked feature in each locality. *Chonetes papilionacea*, *Productus longispinus*, *Pr. semireticulatus*, *Orthis Michelini*, and other fossils also occur.

At Black Hall and Cold Coats, about a mile west of the village of Chipping, the black limestones of the Pendleside Group are seen and quarried. Here, however, the officers of the Geological Survey have not mapped the series.

The quarry at Black Hall mentioned by Phillips (*op. cit.* p. 20) is now disused, but shows the following section :—

[1] 'Geology of Yorkshire' pt. ii (1836) p. 72.

	Feet.
Limestone	5
Black jetty shales	2
Limestone, with crinoidal débris	$1\frac{1}{2}$
Shales, with large limestone-'bullions' or lenticles; *Glyphioceras reticulatum* and *Posidoniella lævis* ...	1
Shales weathering white at the edges, and numerous small black concretions	$6\frac{1}{2}$
Nodular limestone in irregular bands, with crinoid-fragments	$2\frac{1}{2}$
Shales, with irregular large 'bullions'	15
Limestone	12
Black earthy shales.	

Masses of goniatites and shales with *Posidoniella lævis* were obtained on the old débris-heaps. Mr. G. C. Crick has determined the goniatites to be *Glyphioceras nitidum (?)*. The limestones are black or blue, and hard. Phillips figured *Goniatites obtusus*, *G. implicatus*, *G. vesica*, *G. serpentinus*, and *G. spirorbis* from this locality.[1] Mr. Crick retains all these species in his catalogue as *Glyphioceras obtusum*, *Gl. implicatum*, *Gl. vesica*, *Prolecanites serpentinus*, and *Nomismoceras spirorbis.*

About half a mile west of Black Hall is Cold Coats Quarry. Here beds of hard blue or dark limestones are worked for road-metal. The workmen state that goniatites are not infrequent, but none were obtained on our visit. A very interesting bed of black shale, covered with hundreds of specimens of *Posidonomya Becheri*, was, however, seen between two of the limestones. This species was accompanied by *Orthoceras sulcatum*, as it is in the black limestone-beds of Poolvash (Isle of Man). Some of the limestones contained fragments of crinoids and shells. A crushed specimen of a small species of *Rhynchonella* was also obtained from this quarry.

In both the quarries just described the dip shows a secondary fold with an axis parallel to the main one, for the beds are dipping south-eastward.

Thus between Longridge Fell and the grits of Saddle Fell is a complete syncline, the beds reappearing on each side of the axis; and there can be no doubt that the beds of Black Hall and Cold Coats represent the Pendleside Limestone, because of their stratigraphical position, and more especially because of the peculiar and characteristic fauna which they contain.

On the west side of Waddington Fell a small dome of limestone appears at Ashnot, as an inlier surrounded by shales. We are satisfied, both by the appearance of the limestone and the character of its fossils (which are abundant and well preserved), that it is a representative of the Carboniferous Limestone of the Clitheroe type, and not Pendleside Limestone as suggested by the Survey officers. They apparently had no hesitation about accepting the similar domes of Withgill, the Sykes, and Downham as Carboniferous Limestone. Even of Ashnot, Mr. Tiddeman says:—

'It bears a stronger resemblance to the Great Scar Limestone than any other beds which I know in a like position.'[2]

[1] 'Geology of Yorkshire' pt. ii. (1836) pp. 234 *et seqq.* & pls. xix–xx.
[2] Mem. Geol. Surv. 1875 'Geol. Burnley Coalfield' p. 19.

The series of shales with limestones which dip off the dome on all sides are not so well developed as on Pendle Hill, and the shale separating them from the main limestone-mass has also considerably thinned out. The stream west and north of Ashnot Barn shows thin limestones, shales with calcareous 'bullions,' and cherty beds, containing the Pendleside fauna (*Glyphioceras reticulatum*, *Chonetes Laguessiana*, *Athyris ambigua*, and *Posidoniella lævis*).

Between the Withgill inlier (which is of the white, massive Clitheroe type with similar fossils) and the grits of Stonyhurst all the intermediate beds occur. The beds are much disturbed along this line, but in the Hodder, near Hodder Place, is a good section showing dark crystalline limestone with much chert and alternating with shales. An excellent diagram of these beds, reduced from a drawing by Mr. Wm. van Waterschoot van der Gracht, is given by Dr. Henry Woodward in a paper on new Carboniferous trilobites.[1] The following fossils were named by Mr. R. B. Newton, F.G.S., from these beds:—

Fragments of vertebrata:—possibly phalangeal bones of a small reptile (?) and part of the jaw of a small fish (?).
Cephalopoda. *Discites* (*Nautilus*) *sulcatus*.
Orthoceras læve (?).
O. cylindricum (?).
O. pyramidale (?).
Lamellibranchiata. *Entolium* (*Pecten*), sp. nov.
Brachiopoda. *Athyris lamellosa (?)*.
Chonetes (?) sp.
Productus sp.
Polyzoa? *Palæocoryne*. Very doubtful.
Trilobita. *Phillipsia Van der Grachtii*.
Ph. Polleni.
Echinodermata. Numerous ossicles of arms of crinoids.
The coral *Lonsdaleia* is stated to occur in one of the bands of limestone.

From the position of this section, midway between the Carboniferous Limestone of Withgill and the grits of Stonyhurst, its true horizon can be definitely stated (although we know that the beds are interrupted by local disturbances) to be at or about the horizon of the Pendleside Limestone, probably somewhat below it. The species of the various fossils are stated by Mr. R. B. Newton as doubtful, but we do know that the Pendleside Group in very many localities contains *Discites*, two species of *Orthoceras*, *Athyris ambigua*, *Chonetes Laguessiana*, and one or two species of *Productus*.

It is interesting to note that *Phillipsia Van der Grachtii* occurs in the greyish shales which come on some 200 or 300 feet above the limestone of Ashnot. My specimens have been kindly identified for me by Dr. Henry Woodward, F.R.S. Here they occur in a greyish calcareous shale. This trilobite is also found in the shales at Whitewell mentioned immediately below, and at Newton Gill

[1] Geol. Mag. 1894, p. 484.

Behind the inn at Whitewell, on the east side of the road leading towards Slaidburn, numerous small sections are exposed by the streams in calcareous shales with thin limestones. The fauna of these beds is remarkable for the number of lamellibranchs, indicating, we think, sub-littoral conditions; the shales in the Yorkshire Dales, Northumberland, and Scotland, which separate the limestones, also contain faunas of a similar type. The following fossils occur at Whitewell:—

Fenestella sp.
Glauconome sp.
Retepora pluma.
Zaphrentis sp.
* *Ctenodonta lævirostris.*
* *Nuculana attenuata.*
Protoschizodus axiniformis.
* *Parallelodon semicostatus.*
* *P. Geinitzi.*
Edmondia laminata.
Modiola sp.
Pecten sp.
Pteronites angustatus.
Spiriferina cristata.
Spirifera trigonalis.
Sp. bisulcata.
Rhynchonella sp.
Productus punctatus.
Pr. semireticulatus.
Pr. aculeatus (?).
* *Chonetes Laguessiana.*
Orthis Michelini.
* *Glyphioceras spirale.*
* *Phillipsia Van der Grachtii.*
Crinoid-stems.

The species marked by an asterisk do not occur in the Carboniferous Limestone of the Midlands, and the fauna as a whole indicates a marked change from that of the *Productus-giganteus* zone below. The exact relation of the beds just described to the top of the Carboniferous Limestone is not apparent, owing to faulting; but their relation to the grits above them can be easily estimated.

If the simple dissected anticline of Clitheroe be traced northward, it is found to expand so that the central core is exposed over a much wider tract of country, and to form secondary lateral folds. The easternmost of these may be studied in numerous sections between Barnoldswick and Thornton.

The quarries at Rain Hall Rock on the east and Gill Rock on the west are in the same beds, and show the different limbs of the anticlinal fold. In Rain Hall Quarry are seen a series of hard blue limestones, well bedded, separated by well-developed beds and masses of shale, dipping south-south-eastward at a high angle (50° to 75°). Shales and limestones are fossiliferous, and yield the following fauna:—

Crinoid-stems, three species.
Palæechinus sphæricus, plates and spines plentiful.
Productus semireticulatus.
Athyris planosulcata.
Streptorhynchus crenistria.
Conocardium aliforme.
Syringopora geniculata.
Zaphrentis Enniskilleni.

Some of the limestones are composed of crinoid-débris. The arch of the dome is seen in the beck, north of St. James's Church. Gill Rock Quarry gives the following section, dip 63°·5 west of north:—

	Yards.
Shales and thin limestones	25
Limestone	26
Shales	4
Limestone	10
Shales, with thin limestones and barium sulphate...	9
Limestone	36
Shales	to floor of quarry.

Fossils here seem to be very rare and fragmentary.

The section in the railway near Barnoldswick shows a series of limestones and shales, probably belonging to the same series as at Rain Hall. An examination of the railway-cutting 1 mile north of Rimmington Station also shows a similar series to those mentioned above.

North of Pendle Hill the Pendleside Limestone would appear to be very inconstant, being often absent or very slightly represented over large areas.

An interesting lenticular band of limestone appears on the north-western flanks of the Grit Hill from Carlton to Booth Bridge, 1 mile north of Earby. Numerous sections in this patch show a good deal of disturbance, and thinly-bedded limestone (hard and often conchoidal in fracture) and shales. Fossils are rare, one fragment of *Orthoceras Steinhaueri* being the only organism obtained.

The quarry near Elslack Free School shows thinly-bedded contorted limestones, and in the quarry in the field south-west of the railway ('dip-mark' 55° on the 1-inch Geological Survey map) the beds are almost vertical, but the section is small. Better sections, however, are seen in the streams which unite about a quarter of a mile north of Yellison House. Here is a well-marked anticlinal fold, and a feature is made by it along the axis of fold. A small quarry in the same rock at the head of Denindale (dip-mark 30° south-east on the 1-inch map) shows bands of chert in the limestone.

It is quite probable that this band represents the Pendleside Limestone. The presence of *Orthoceras Steinhaueri* and petrological evidence favour strongly this view.

The Lothersdale Valley is much complicated by faults, but there is a large central mass or dome of limestone dipping south-eastward and north-westward, of very considerable thickness: this is largely quarried at Raygill Delph and Hawshaw Delph. The quarry at Park Head shows much the same section of limestone also in the form of an anticlinal fold, but in addition shows a small section of beds above it: black shales with *Posidonomya Becheri*, *Posidoniella lævis*, *Orthoceras Steinhaueri* (crushed), *Glyphioceras bilingue*, and *Gl. spirale*.

Fossils are very rare in all the quarries, but fine encrinital and shell-detritus is met with. In the south-western part of this basin, a quarry on the road to Bleara Low (marked Broom Quarry) still shows an anticlinal fold in the limestone with the axis in the same direction.

It seems to us that the examination of the ground does not bear out the mapping (of the 1-inch survey), but rather shows one long central axis in the same beds from Park Head by Raygill, Hawshaw, and Bleara, the relations of the Bleara and Hawshaw beds being complicated by faulting. West of Dale End village, on the south bank of the stream, is a small section which shows

Dark thinly-bedded limestone, 20 feet;
Shales;
Reddish-brown shales;
Calcareous shales;

dipping 70° south-eastward. Followed westward, the stream exposes a considerable thickness of shale, which is faulted against thin black shales. This series is certainly distinct from the Park Head Limestone, and represents the Pendleside Group in this small basin. Other evidence of these beds is obtained in streams on either side of the valley.

The district between Skipton and Bolton Abbey is much disturbed, but certain sequences can be well made out. Here is the central core of limestone, consisting of a high-pitched anticline of thin and well-bedded limestones with the axis ranging east and west, very slightly south and north, well seen in the great quarries on Embsay, Skebeden, and Hambleton Quarry, near Bolton Abbey railway-station. Fossils are rare, but those obtained are characteristic of the Carboniferous Limestone. A brook-course, which runs south-south-eastward from Gillhead, shows a series of shales and two or three bands of thin limestone repeated by folding. These limestones are seen again between Eastby and Embsay, a brook giving a fair section from the grits to the anticlinal core of limestone. There can be little doubt that these thin bands are the representatives of the Pendleside Limestone. The axis of this fold lies nearly in a direct line with that of the Lothersdale Valley, and both the folds are therefore probably due to the same series of disturbances.

A quarry at the point where the road from Draughton village approaches the Bolton Abbey & Skipton Railway shows the thick undivided limestone-series, overlain conformably by 12 feet of thin limestones, shales, and sandstones, and above these 12 feet of micaceous shales. A fine specimen of the spine of *Ctenacanthus tenuistriatus* was obtained on our visit here, in the calcareous shales just above the mass of limestone.

Portions of Sheets 60 and 61.

We now pass to a very interesting tract of country, which lies in the southern halves of Sheets 60 & 61 of the 1-inch Geological Survey Map. In Sheet 60 the greater part of the area is mapped as Yoredale Shale, with here and there a few sporadic patches of limestone; but examination of the ground and numerous small quarries

seem to show much more limestone than is accounted for on the map, and we are inclined to believe that the Carboniferous Limestone occupies nearly the whole area.

Commencing on the west, the side of the fell at Tosside shows, at Knotts, a massive white limestone cropping out below the grit as a lenticular patch; but, owing to the absence of stream-sections, its downward extent cannot be determined. It is lithologically quite different from the Pendleside type, and contains a characteristic Carboniferous-Limestone fauna (including *Chonetes papilionacea* and *Productus giganteus*).

About three-quarters of a mile north of this is an exposure behind the farm at Brockthorns; the beds are nearly horizontal, and consist of shales and thin limestones, with a thick limestone at the base, 6 feet of this being exposed. An extensive list of fossils was obtained from these limestones, belonging to the *Productus-giganteus* zone. A narrow lenticle of limestone is mapped at about 1½ miles northwest of this; the quarry-sections show beds similar to those at Brockthorns.

The quarry at the dip-mark, north of the word 'Bollands,' shows 15 feet of solid limestone, base not seen, covered by a few feet of shales and thin limestones.

At Pythorns, a little more than a quarter of a mile farther east, is another exposure of well-bedded limestone, with bands of apparent brecciation and a conglomeratic bed at the top, about 3 feet thick, crammed with rolled fossil débris. A similar bed occurs at Brockthorns; it is covered by a few inches of shale, and recalls the so-called 'beach-bed' of Castleton. It is seen in many other quarries about this horizon, and we regard it as of extreme importance as a stratigraphical line.

Some 2 miles still farther east is the quarry at Teenley Rock in well-bedded limestone, the beds being nearly horizontal. Fossils are not plentiful, but here, as at Pythorns, etc., they are of the Carboniferous-Limestone type, and *Productus giganteus* occurs.

Between Teenley and Pythorns the limestone and shales are seen in the stream near Becks Brow Bottom; and a sulphuretted-hydrogen spring here seems to indicate a roll and temporary disappearance of the massive limestone from the surface.

East of the Ribble is a patch of country, bounded on the north and east by the Hellifield & Skipton Railway. The upper beds of the massif of limestone seem to cover the whole of it, and even where the quarries are absent the appearance of the ground favours this view. Massive bedded limestone is seen in a quarry near Bell Busk Station, and again in another one rather less than a quarter of a mile west of Bell Busk Viaduct. The latter yielded *Chonetes papilionacea*, *Spirifera lineata*, *Syringopora geniculata*, *Cyathophyllum* sp., and crinoid-stems.

Near Cold Coniston the limestone occurs in a series of small domes or knolls, one of which is bisected by the Skipton and Settle road at Fogga. The upper part of this limestone is massive, white, and not clearly bedded, but the lower beds are more regularly

stratified, and seem to form the upper portion of a series of such beds which occur on the side of the hill 200 yards west of Fogga, where some 30 feet of them are exposed in a quarry dipping at 30° north-north-eastward, that is, under the Fogga rocks. Both these quarries contain the typical Carboniferous-Limestone fossils.

Sections showing a small thickness of compact limestone overlain by calcareous shales also occur at Old Rock Plantation and within a short distance of it; *Productus giganteus* is found in the limestone along with *Cyathophyllum Stutchburyi* and crinoid-débris; the dip varies from 10° to 20° in a northerly direction. Three quarries in the compact limestone, containing the same fauna, lie on the high banks of the northern tributary of Swinden Gill: the lowest of the three shows 18 feet of well-bedded thick limestones without shales; south of this is a gap in the sequence, but about 100 yards farther south the black shales come on, the exact position of which is doubtful. A series of dark limestones of Pendleside type occurs in them immediately east of the railway in Swinden Gill.

Newton Gill, 1 mile east of Long Preston, gives the following section, kindly measured for us by R. Hornby, Esq., M.A. The upper beds dip 10° northward, and the section commences about a quarter of a mile south of the Grit-outcrop, the succession between the Grits and this point being sandstones, black shales, and hard muddy shales without fossils.

	Feet.	Inches.
Limestone with crinoids	1	0
Gap (presumably shale from the nature of the ground)	30	0
Thin shales	3	0
Shales passing into limestones	0	9
Shales	2	6
Thin limestone	0	6
Shales	3	0
Gap; boggy ground	45	0
Shale.		
Thin limestone	0	2
Hard shale	1	0
Thin limestone	0	4
Gap	12	0
Shale	4	0
Gap	30	0
Shale, with *Productus longispinus*, *Zaphrentis* sp., and crinoids	1	0
Obscure	12	0
Shale, with *Zaphrentis* and crinoids	12	0
Bed, with nodules (sp. gr. 3·3)	15	0
Gap	9	0
Flaggy shales	9	0
Gap	18	0
Very thin limestones.		
Shales with thin limestone	3	0
Hard, compact sandstone	0	4
[About here the dip becomes steeper, 30° northward.]		
Fine, thinly-bedded sandstone with shaly partings.	18	0

	Feet.	Inches.
Shales	15	0
Sandy shales, with a 9-inch sandstone	9	0
Gritty sandstone	9	0
Sandstone	9	0
Massive sandstone	12	0
Flaggy shales, with *Posidonomya Becheri*	12	0
Mudstone	0	8
Shales	3	0
Fine-grained sandstone	3	6
Shale	9	0
Sandstone	1	0
Flaggy sandstone	18	0
[At this point is the flood-rail in the stream.]		
Massive fine-grained sandstone	9	0
Sandstone with shaly partings	3	0
Shale	10	0
Shale with thin sandstone	9	0
Sandstone with boxstones	0	8
Fine grey paper-shales	2	9
Waterfall over massive sandstone	6	0
Shaly parting	0	6
Sandstone	0	8
Shaly sandstone	0	6
Compact sandstone	14	0
Micaceous dark-grey sandstone	0	8
Flaggy shales	4	0
Grey paper-shales	9	0
Black shales	10	0
Lenticular bands of limestone	0	3
Hard muddy shales; Fine shale; Gritty shale	15	0
Limestone, with crinoid-fragments	0	1
Shales, with *Aviculopecten papyraceus*	0	6
Limestone with *Phillipsia Van der Grachtii*, *Goniatites*, three species of gasteropods, and a fish-scale		
Black shales	6	0
Limestone	0	3
Calcareous shale	1	0
Fossil-band	0	4
Shale	0	3
Limestone	2	0
Shales with *Aviculopecten papyraceus*, *Posidonomya Becheri*, *Posidoniella lævis*, and *Discites* sp.	6	0
Gap	120	0
Limestone-conglomerate, rolled shells and fragments, *Productus Cora*, *Spirifera*, and corals.		

The last-mentioned bed is so remarkably like the conglomerate of Brockthorns and Pythorns, that the above section may be considered to give a very fair representation of the whole series between the limestone-massif and the grits.

In the becks on the western flank of Flasby Fell we find a typical Pendleside sequence; the massive limestone is not exposed here, but its presence seems to be indicated by a strong feature running along the lower flank of the hill, and a gamekeeper told us that he

had often come down to it when digging. The shales of Flasby Fell are of interest, because it was here that Phillips obtained some of his goniatites. We found fossils of the Pendleside fauna in abundance, in the shales and limestones just above Thorlby, but the majority were much crushed. The beds in the gill in Sulber Lathe and in the stream north of Flasby Hall have similar fossils.

The 'Knoll' Area of Cracoe and Thorpe.

Extending from Greenhow on the east to beyond Cracoe is a stretch of country exhibiting very striking and peculiar contours; in it appears a more or less linear series of rounded limestone-knolls which have already been very fully described by Mr. Dakyns, Mr. Tiddeman, and Mr. Marr. It hardly forms part of the scheme of this paper to enter into the discussion concerning the origin of these structures, but it is imperative that we should record our opinion as to their horizon.

Mr. Tiddeman has taught for many years that the limestone which forms the knolls in this area is on the horizon of the Pendleside Limestone, and that it formed original reefs on the latter, subsequently surrounded and enveloped in shales. This view of the horizon of the 'knoll-limestone' has been accepted and followed by other geologists and palæontologists, with the result that the fossils which occur in it have been assigned to the Pendleside Limestone. For our part, however, we are quite unable to believe that the knoll-limestones of this area are Pendleside Limestone; on the contrary, we are of opinion that they are part of the upper beds of the massive limestone, which, even so near as Clitheroe and Downham, Mr. Tiddeman admits to have formed knolls of precisely identical character with similar fossils. We have founded this opinion on both stratigraphical and palæontological grounds.

The occurrence of well-bedded with massive, obscurely-bedded limestone is not peculiar to this district, but is a fairly common condition of the upper portion of the undoubted Mountain-Limestone tracts of Clitheroe, North Staffordshire, and Derbyshire. In each of these districts the obscurely-bedded limestone has the same lithological characters, and weathers in the same manner into knoll-like hills. We can find no evidence for the assumption that these rest on the Pendleside Limestone, for nowhere is the base of the knoll-forming limestone seen; on the other hand, limestones of the Pendleside Group may be observed, resting in their natural position upon them. For example, in the depression between Butterhaw and Skelterton, in a fairly large swallow-hole (one of a series which marks the junction of the shale and limestone), we find shales and limestones dipping at an angle which would carry them over the limestones of the knoll.

The palæontological evidence is no less clear, and even more satisfactory. The fossils of the Cracoe knolls present a facies identical with those of Clitheroe, Castleton, or Thorpe Cloud in the Carboniferous Limestone (see Appendix A, facing p. 402); while in the shales resting upon them, in the swallow-hole mentioned above, we found *Posidoniella lævis*, *Posidonomya Becheri*, and *Glyphioceras reticu-*

latum—that is to say, in their proper position with respect to the knoll-forming limestone below.

Of the two conflicting views of the origin of the knoll-structure, namely, the 'reef-knoll theory' of Mr. Tiddeman [1] and the 'thrust-hypothesis' of Mr. Marr,[2] we are inclined to accept the former, after certain modifications. We agree with Mr. Tiddeman that there is something essentially reef-like in the mode of formation and shape of the knolls and in the materials of which they are made; they seem indeed to closely resemble certain reef-structures now forming on the East Coast of Africa. At the same time, we cannot see in them a structure such as he demands, namely, a horizontal central bedding, with peripheral periclinal slopes. Hill Skelterton, Swinden, and Butterhaw, and a smaller unnamed hill to the west, are distinctly bedded throughout, without any quaquaversal dips; while on Hill Stebden and El [Hill?] Bolton the bedding seems too obscure to permit of the formation of any definite decision. On Keal Hill the principal direction of dip seems to be to the south-east, and this, with a very small fault, would allow the beds to pass regularly beneath the Grits of Burnsall Fell. Again, we have not yet been able to find any of the conglomerate which, Mr. Tiddeman says, fell down from the reef and became embedded in the shales round the base. That such a conglomerate should exist is exceedingly probable, yet at the best exposure mentioned by him, in the stream-section east of Keal Hill, we failed to discover it. What we found was the following section:—

	Feet.
Shales	20
* Band of (crushed?) limestone	3
Dark shales	3
* Band of crushed limestone, with *Cladodus*	3
Shale, with *Discites* (*sulcatus*?)	1
Black shale, with *Posidoniella lævis* and crushed goniatites.	

The bands of limestone marked with an asterisk probably represent Mr. Tiddeman's 'conglomerate,' but they appear to us to be bands of dark limestone, in parts crinoidal, slightly shattered, probably by the fault suggested above. They do not in any case suggest the appearance, or contain the fossils, of the knoll-limestone.

With regard to Mr. Marr's views, we admit that anyone coming to the examination of these curious structures with a *vis a tergo* produced by an hypothesis of thrusts, would see much in his favour, but nothing, we believe, that could be taken as conclusive evidence or that could not be matched in many of the similar limestones in undisturbed areas.

[1] Brit. Assoc. Rep. 1889 (Newcastle) p. 602; Brit. Assoc. Excursion Guide, Leeds, 1890 pp. 47 *et seqq.*; Comptes-rendus du IVème Congrès géol. internat. 1888 (London) pp. 321–22 [publ. 1891].

[2] Quart. Journ. Geol. Soc. vol. lv (1899) p. 327; see also Mr. Tiddeman's criticism, Geol. Mag. 1901, p. 20.

Mr. J. R. Dakyns, who surveyed the district in which the knolls occur, says[1]:—

'We have, moreover, independent evidence that the surface of the limestone underneath the overlying shales and grits is uneven. On Simonseat, a Millstone Grit fell on the east side of the Wharfe, there are some swallow-holes, which show that the limestone is present at no great distance below the surface: but below Thorpe Fell is a thickness of at least 450 feet of shales overlying the limestone. . . . . It does not seem possible that swallow-holes should be formed into limestone through anything like 400 feet of shale; it is more than probable that under Simonseat the limestone is much nearer the Millstone Grit than it is in other places: that is, the limestone-surface is very uneven.'

There may, of course, be some unevenness of the limestone-surface, but the facts observed by Mr. Dakyns point rather to the rapid thinning-out of the Pendleside Group here: between Burnsall and Greenhow, little or no measures separate the grits from the limestone; also in the Nidd Valley and Upper Wharfedale, the grits are separated by only a few feet of measures from the limestone below. For instance, in the Nidd Valley at Lofthouse the following section is exposed:—

	Feet.	Inches.
Millstone Grit.		
Black laminated limestone	5	0
Shale	1	2
Blue limestone	6	0
Shale, with thin band of limestone.	4	6
Massive limestone.		

We have not been able to search these limestones for fossils, but it would seem not improbable that the whole of the Pendleside Group is represented by these few feet.

Sections examined for us by Mr. H. B. Muff, F.G.S., in the River Wharfe just below Burnsall Village and in the small beck called Waterspout, south-west of Burnsall, showed shales and limestones with Pendleside fossils.

On the north side of the anticline, beds of shale with soft dark limestone are seen in the southern bank of the Wharfe, immediately south of the Linton stepping-stones, also with Pendleside fossils, and traces of a similar fauna occur in the shales near Hebden in Wharfedale.

That the Carboniferous succession of South Craven differs very considerably from that seen in the flanks of Ingleboro', Penyghent, and the fells in the upper part of Wharfedale is apparent; and it is commonly taught that the change of the southern into the northern type is sudden and without any gradual passage from one to the other. It is also believed that this sudden change occurs and is connected with the great east-and-west system of faults called the Craven Faults. Mr. Tiddeman has advanced the view that the change was entirely due to the fact that the Craven Faults were in existence and in process of development during the deposition of

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 360–61.

the Carboniferous Limestone, and that the absence of shale and sandstone in the southern type was due to a considerable difference of level at or about the faults, which in some way fixed a line beyond which the different sediments from the north and south could not pass.

The statement that the change from the northern to the southern type is sudden, and that the change takes place at the Craven Faults, is, however, not borne out by field-work.

The sections described in the foregoing pages of the upper part of the Carboniferous Limestone at Barnoldswick, Gill Rock, Rimmington railway-cutting, Whitewell, and the large quarry south of Chipping, at least 10 miles south of the lower limb of the Craven Faults, show a tendency to change, to a certain extent, to the northern type over this area. On the other hand, there is no sign of a change to the northern type in the fine and extensive sections of limestone from Gordale Scar by Malham, Settle to Giggleswick; and, indeed, north of the faults indications of the change are entirely absent along the eastern Limestone Grit margin for several miles. Here, as pointed out by Phillips,[1] the change to the Yoredale Series comes on gradually, by the intercalation of beds of shale and sandstone in the limestone which farther south was one mass. He shows that this series increases rapidly to the north, and that the beds which measure 277 feet in Great Whernside thicken to 510 feet at Starbottom.

Further, we know that the Yoredale Series as we see it in Ingleboro' and Penyghent, becomes much more complicated as it passes northward, there being more separate definite beds of limestone capable of being mapped and traced over large areas; and that the Lower Scar Limestone, or all that remains of the great mass of limestone south of the fault, itself becomes subdivided as it passes northward to Westmoreland and Northumberland, forming the Melmerby Scar Series of Shap and the Cross-Fell range.

On the other hand, too, the masses of limestone to the north-west, in the Barrow, Burton-in-Kendal, and Kirkby Lonsdale districts, have certainly not assumed the northern type.

The shale-country round Whittington and Hutton gives several sections, and shows only a single bed of limestone separated from the main mass. The fauna of these beds, however, appears to be distinct from that of the Pendleside Group, the limestone and shales yielding a typical Carboniferous-Limestone fauna.

A small stream east of Borwick Hall gives a section of some 200 feet of shales with thin sandstones.

We examined the bed of limestone north of Whittington village, and found an extensive section in the stream and a neighbouring quarry. The limestone was yellowish, about 25 feet thick, and had shales above and below it. It contained crinoids, a fish-tooth, and shell-fragments; but the shales were more fossiliferous, yielding crushed *Productus* and other limestone-forms.

[1] 'Geology of Yorkshire' pt. ii (1836) p. 32.

·na was obtained in a stream-section a quarter of a ·llet Hall, in beds presumably midway between ·and the main mass. The bed was a calcareous ·d contained—

·ia.	*Athyris planosulcata.*
	Rhynchonella pleurodon.
	Edmondia unioniformis.
	Sanguinolites striatolamellosus.
	Monticulipora.
	Fenestella.
	Crinoids.

·the grit-outlier of Black Hill, 1½ miles ·, is much confused by faults, but the position ·stone and its relations with the grit on the west ·disturbed. The section is exposed in the bed of a ·quarter of a mile west of Black Hill, and shows a hard blue ·one of some thickness, overlain by shales full of ferruginous ·ncretions. The limestone yields *Productus latissimus*, *Streptorhynchus crenistria*, and crinoids. The presence of the first-named fossil determines the connection of this bed with the Yoredale Series of Wensleydale, and shows that it may be regarded as part of the Carboniferous Limestone separated from the mass by a wedge of shales which thickens northward.

A careful survey of the ground, therefore, at once demonstrates that the Craven Faults have nothing whatever to do with the change of type of the rocks, because the change begins some distance south of the faults, is certainly not apparent between the faults, and along the western boundary of the limestone comes on very gradually; and in no place within a mile or so of the northern limb of the fault is the change apparent.

The southernmost point where the northern type is fairly developed is in the flanks of Ingleboro' and Penyghent, and unfortunately denudation and earth-movements have completely removed the beds which would have afforded the actual evidence of the change between Settle and this line.

The theory that the change from the northern to the southern type of Carboniferous rocks is abrupt and without a passage, creates other difficulties. It is known that the fauna of the Carboniferous Limestone practically ceases with that formation, only very few species recurring in the overlying beds; and that the fauna of the Yoredale limestones and shales of the northern type is practically identical with that of the Carboniferous Limestone, and totally different from the beds of the southern type to which the term 'Yoredale' has been applied. Could a growing fault annihilate a fauna in any district, along an almost mathematically precise line, unless the extent of the fault were so great and the formation so rapid that it practically altered the conditions of environment

so thoroughly as to be incapable of permitting the fauna to live any longer? But the Craven Faults cannot be very extensive as to throw. At the eastern end of the fault and near Hebden the throw is only of very limited extent, and as far west as Malham the fault is in the same series of beds. The throw of the northern fault is probably greater, but is not extensive: for quarry-sections, and a boring at the base of Mr. Delaney's quarry (west of Stainforth Station and south of the faults), show the following succession, which was communicated to me by the Rev. A. Crofton, late rector of Giggleswick:—

	Feet.	Inches.
White limestone, with *Productus giganteus* and corals		
Clay-parting		
Limestone, with *Productus Cora*		
Hard blue limestone, with *Bellerophon, Productus giganteus*, and corals	40	0
Thin coal and seat-clay	0	0½
Limestone	0	0
Thin coal and seat-clay	0	1
[At this point rise several springs.]		
Hard rock, calcareous	2	6
Shaly parting	0	0
Hard rock	2	11
Clay with trace of coal	1	1½
Clay with coal	1	2
Shale	1	2
Hard rock	2	0
Shale	0	5
Hard slaty rock	1	2½
Red clay	0	0
Lenticles of fossiliferous limestone	1	8
Rock	2	6
Rock	1	5½
Hydraulic limestone	1	11
Clay like hard putty	1	2
Rock and shale	1	5½
Calcareous conglomerate	2	0
Silurian slates, nearly vertical.		

Here we see that the top of the Silurian floor south of the fault is not far below the sole of the limestone-quarry.

Another difficulty which arises, if the theory be true, is to account for the great difference in the depth of deposit within a distance of between 2 and 3 miles, supposing that the Great Scar Limestone (only 500 feet thick below Ingleboro') is the equivalent of the mass of limestone at Settle, Malham, Cracoe, and Clitheroe. And, on the other hand, what has happened to the 1500 feet of beds with seven thick limestones which are found in Wensleydale; and why is only one limestone found between the 'massif' and the grits at Black Hill?

A further difficulty arises also as to the identity of the various beds of limestone in the Yoredale Series. The Grit, which caps the country intersected by the great dales, forms a good datum-line above: the base of the Yoredale Series, however, is variable, and the

number of limestones between the grits and the 'massif' or Great Scar Limestone—for this is the term applied to the variable quantity of undivided limestone—is not constant, but increases, almost indefinitely, as the beds pass northward.

At Ingleboro' the fifth bed of limestone below the Grit is called the Hardraw Scar; but in Wensleydale the fifth bed, reckoning downward, is called the Simondstone, and the sixth is called the Hardraw Scar. On reckoning from below, while at Ingleboro' the Hardraw Scar Limestone is the first limestone above the main mass, near Hawes another bed, the Gayle Limestone, is found in the shales separating them.

Up to the present, the fauna of the shales and limestones of the southern type has not been found north of the Craven Faults, although it seemed to us probable that some remnants might occur in the shales and upper limestones connected with the Crowstones, which come on below the grits in the valleys of the Eden and the Swale. Careful and repeated examination has failed to show the Pendleside fauna at this horizon. On the contrary, these beds contain a fauna identical with that found in the shales of the Carboniferous Limestone Series of Scotland.

The Felltop Limestone of Northumberland, too, seems to have a Carboniferous-Limestone fauna, and, according to Prof. Lebour, contains *Productus giganteus*.[1]

A complete and important section of the beds between the Millstone Grit of Nine Standards Fell, south-east of Kirkby Stephen, as shown in Faraday Gill, has been published by one of us,[2] but no fossils of the Pendleside type were obtained there. A suggestive bed of limestone associated with chert occurred in a sandstone series some little distance below the base of the grits.

A good section in the same beds was obtained in Far Cote Gill, on the eastern flank of Swarth Fell, nearly opposite Hell Gill:—

Millstone Grit Series.
Gap.
Black shales with bullions; no fossils found.
Blue limestone, with conchoidal fracture. Compact, weathering yellow; no fossils found, 6 feet.
Gap.
Sandstones with *Stigmaria*.
Sandy shales.
Black compact shale, almost a fissile limestone, with *Spirifera bisulcata*, *Productus semireticulatus*, *Chonetes Laguessiana*, *Athyris planosulcata* or *ambigua*, *Camarophoria crumena*, *Ctenodonta lævirostris*, *Nuculana attenuata*, *Protoschizodus axiniformis* (large), and *Pleurotomaria* sp.
Shales.
Thick limestone, probably the Main Limestone.
Black shales with *Productus semireticulatus*.
Massive limestone, Underset Limestone, with *Productus giganteus* and large corals (*Cyathophyllum*).

[1] 'Outlines of Geol. of Northumberland & Durham' 2nd ed. (1886) p. 110.
[2] Pal. Soc. Monogr. vol. liii (1899) 'Brit. Carb. Lamellibr.' p. 358.

North Staffordshire and Derbyshire.

The Carboniferous succession in North Staffordshire and Derbyshire is fairly constant over the whole district, and consists roughly of:

MILLSTONE GRIT	A series of grits and quartzites, separated by masses of shale with occasional marine bands.
PENDLESIDE GROUP	A series of dark shales with hard dark limestones containing the typical fauna.
CARBONIFEROUS LIMESTONE ...	A practically undivided mass the base of which is nowhere seen, said to be 3000 feet thick.

Local variations occur in the Grit Series; some beds disappear altogether as they pass southward and westward, and the Pendleside Group too is subject to local variations in thickness.

The tectonic structure of this area is due to a series of parallel anticlinal and synclinal folds, very little interfered with, on the whole, by faults which affect the various members of the series. The axes of these folds range almost due north and south, the orographic axis being much nearer the east than the west.

Starting on the west with the escarpment of Congleton Edge, where the greater part of the series is exposed, from the Carboniferous Limestone to the Lower Coal-Measures, we find the synclinal trough of the Biddulph Coalfield. This is succeeded by the anticline in the shales and Farey's Grit on Biddulph Moor, best seen at Gun Hill. Farther east is the syncline of the grit-basin of Horton. This is succeeded by the syncline of the Roaches and the Goldsitch Coalfield, which is followed by the anticline of Morridge, exposing the Pendleside Group, and 2 miles south of the section exposing even the top of the limestone. Farther east again is the small syncline formed by the outlier of Sheen, below which all the beds rise in succession, exposing the great mass of limestone, between Hartington and Matlock, as an anticline. Beyond Matlock the upper beds recur in series to form the western limb of the Derbyshire Coalfield. Transverse sections farther north and farther south are much simpler, and show only two or three parallel folds.

Careful measurements at Matlock, south of Youlgreave, between Sheen Hill and the limestone-boundary north of Hartington and at Congleton Edge, show that the measures between the limestone and Farey's Grit cannot be more than from 500 to 1000 feet at the most. This fact is borne out by the section north of Doveholes, and also by measurements in the neighbourhood of Eyam.

The section half a mile north of Doveholes supplies the following details. It occurs along the line of the tramway to Peak Forest, and is continued by the section in the London & North-western Railway just north of the tunnel, the escarpments of the grits forming features in the hill westward. The tramway-cutting shows massive, well-bedded, crinoidal and shelly limestone dipping west by north at 15°:—

	Feet.	Inches.
Dark shale	20	0
Hard limestone	0	6
Shale	0	4
Hard limestone	0	9
Carbonaceous shales	1	0
Light grey fossil-limestone	several yards	
Crinoid-beds	100	0

The railway-cutting from bridge no. 74 to the tunnel, shows beds slightly above the foregoing, and gives 30 to 40 feet of dark calcareous shales, enclosing bullions and lenticles of hard dark limestone with *Aviculopecten papyraceus*, *Posidoniella lævis*, *Glyphioceras bilingue*, and *Gl. reticulatum*. The officers of the Geological Survey indicated, however, a fault running parallel to the railway, though we have been unable to find any trace of its existence.

A fairly complete section of the series from the Coal-Measures to the Carboniferous Limestone is found at Congleton Edge (Cheshire), details of which were published in a paper by Mr. Walcot Gibson and one of us.[1] In this area the chief fossiliferous bed is a shale with large bullions; but at times it consists of a hard, compact, dark limestone showing conchoidal fracture and occurs below the Third Grit. Lower down, and nearer the top of the massif of limestone, a series occurs of thin limestones with shales containing the Pendleside fauna, well-developed.

Beds yielding the typical fauna are to be seen in the River Dane, a quarter of a mile east of the viaduct, and farther north, about 2 miles south-east of Macclesfield, on the stream-courses near Sutton. The same beds are well exposed in the stream east of Bosley Minn, which shows the bullion-bed and its associated limestones.

The higher bed of this Group, very rich in fossils, is exposed on the southern bank of the Dane, a little distance west of the salmon-ladder; but here the bed has slipped, owing to disturbances, and is almost vertical. These beds have yielded the usual Pendleside fauna: the cavities of the cephalopods are full of a mineral oil.

The Dane and its tributaries at Bosley afford good sections of the Group, bullions yielding the same fauna and fish-remains.

The evidence of the sequence of strata between the northern boundary of the limestone and the Kinderscout Grits is none the less apparent, though complicated by erosion and landslips. Fossil evidence and the peculiar nature of the limestones demonstrate the presence of the Pendleside Group between Lose Hill, Mam Tor, and Trey Cliff. In the Edale Valley, too, the beds are exposed in the streams from about a quarter of a mile east of Edale-Head House to 1 mile beyond Edale Chapel, the characteristic Pendleside fossils also occurring.

The shales at the base of Mam Tor have yielded *Aviculopecten*

[1] W. Gibson & W. Hind, Quart. Journ. Geol. Soc. vol. lv (1899) pp. 548–55.

papyraceus, *Posidoniella lævis*, *Leiopteria longirostris* (with a very slender long process to the wing), and *Glyphioceras reticulatum*.

Along the northern and western border of the Mountain Limestone a most interesting bed of rolled shells and fragments of limestone occurs at or near the top, sometimes interstratified with limestone, as at Castleton and Waterhouses, at others separated from the main mass by a few feet of thin limestones and shales. This bed at Castleton and along the northern boundary has been described fully by Messrs. J. Barnes & W. F. Holroyd.[1] I have been able to trace this bed over a great part of North Staffordshire and Derbyshire, in fact wherever the uppermost beds are exposed. It is well seen in a small quarry-section about 200 yards south of the road between Warslow and Hulme End, where it occurs interstratified with shales and thin limestones, separated by a short piece of rising ground from an important series of quarries farther south, showing the limestone-succession for several hundred feet. The upper beds of this series are thin, whitish, and contain much chert; the lower are thicker and crinoidal. There is a marked absence of shale.

A section in the same beds is seen in the gorge of the Manifold from Apes Tor towards Ecton Bridge. The section is much folded, and shows the upper beds of the 'massif' of limestone:—

	Feet.
Rolled shells and fragments of limestone ... [Fauna typical of the Carboniferous-Limestone Series.]	3
Shales with thin limestones	60
Limestones becoming more massive and free from shales	50
Fairly thick limestone	21
Thinly-bedded limestones, with shaly partings	45

The section here is repeated and faulted by many folds, but the foregoing details would seem to imply that these beds come on above the series shown in the Warslow Quarries. These are seen in the gorge farther west, but owing to the faulting and twisting of the intermediate section, cannot be considered to afford in this spot any evidence of the real succession.

The beds just above the limestone, which we may regard as passage-beds and coming in at the top of the limestone, are quarried at Butterton Moor, and show a section of about 20 feet of shales with thin sandstones and limestone, resting on a thick limestone, the base of which is not seen. This series evidently belongs to the base of the Pendleside Group, and we regard the beds as being on the same horizon as those in the Tissington railway-cutting, to be mentioned below.

The stream which drains the eastern slope of Morridge gives good sections of the Black Limestone Series; and from that afforded by the stream which rises about half a mile west of Blakemere

[1] Trans. Manch. Geol. Soc. vol. xxv (1897) p. 119.

House, showing about 300 feet of shales and limestones, we obtain the following succession:—

		Feet.
Pendleside Group.	Dark hard limestones, with conchoidal fracture; finely stratified	40
	Shales, with occasional thin limestones	200
	Dark hard limestones, with conchoidal fracture; stratification obscure	50

Black shales occur beneath these limestones, but unfortunately there is much disturbance and the beds below are repeated and faulted. At any rate, it is impossible for the top of the mass of white limestone to be very far below this point.

The stream near Mixon Hey, in these beds, yields a rich fauna with *Posidonomya Becheri*.

The section exposed by the new Ashbourne & Buxton Railway, reports of which have been published independently by Mr. H. H. Arnold-Bemrose and one of us,[1] shows a succession of limestones and shales with volcanic ashes and tuffs at the top, much contorted and folded. The section is as follows:—

	Feet.	Inches.
Shales, with eighteen bands of thin limestone yielding *Aviculopecten papyraceus*, *Posidonomya Becheri*, & *Posidoniella lævis* in the upper part	23	0
Chert	0	3
Calcareous shale	0	4
Massive shelly limestone, with *Productus giganteus*, etc. and fish-teeth; in places a shelly conglomerate	11	0
Shales and bands of limestone	57	9
Hard grey limestone	3	0
Shales with limestones	11	0
Shale	0	6
Chert	0	3
Hard limestone	2	0
Shales and limestone	10	7
Earthy limestone	1	0
Shale and marl	8	0
Volcanic series	144	0

The foregoing section shows the junction of the two faunas; and the varying lithological character of the members of the series indicates that they form a well-marked set of passage-beds between the Pendleside Group and the Carboniferous Limestone.

The sections in the various quarries at Waterhouses show a considerable series of thinly-bedded limestones with chert-bands, large corals, and many fossils, and a well-marked bed of rolled shells and limestone-pebbles at the top. These beds belong to the *Productus-giganteus* zone (that fossil is plentiful in the top bed); and it would seem that no thickness of shale was deposited between

[1] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 224-37; Trans. North Staffs Field Club, vol. xxxii (1897) p. 114.

the limestones at this spot, for there is no indication here of passage-beds.

The junction of the limestone and the shales above is not quite clear. In the bed of the Hamps, immediately beyond the bridge and below the schoolhouse, is exposed a thick massive limestone dipping 40° south-westward. The overlying beds are obscured, but a few yards farther up the stream a continuous section in black shales, with occasional thin calcareous beds and strings of calcareous concretions, is seen for some little distance. So far as we have been able to search them, they yield only *Posidoniella lævis*, *Glyphioceras bilingue*, and fish-remains. The beds seem to belong to the upper portion of the Pendleside Group: the Pendleside Limestones have probably been cut out by a fault.

About 1½ miles west of Waterhouses the Leek road crosses the Hamps, in which are exposed a series of fine grits and shales, probably representing the base of the Millstone-Grit Series. It is to be hoped that the excavations for the new railway, soon to be built along this valley, will settle the succession definitely.

The Marsden and Saddleworth District.

Between Castleton and Clitheroe the Carboniferous Limestone is not exposed, and the intervening country consists chiefly of Millstone Grits and Coal-Measures. Two valleys, however, the tributaries and upper streams of the Mersey and the Calder, have cut down to the shale-and-limestone group (the Pendleside) below the grits, and show good sections of the Pendleside Group.

Messrs. J. Barnes & W. F. Holroyd [1] have given a good description of the beds as they occur at Mossley, Saddleworth, Diggle, and Marsden, and have been able to record very complete collections of fossils from this horizon. The fossiliferous beds consist of shales, with courses of dark hard limestone and bullions, and they have demonstrated that certain beds must have contained the Coal-Measure genera *Carbonicola* and *Naiadites*. We have had the opportunity of repeatedly examining the collections made by those two gentlemen, and are convinced that these genera do not occur in the same beds as the other fossils, because the matrix is not the same. Unfortunately neither of these genera has been found *in situ*, for the specimens were collected from the waste-heaps from the tunnel beneath Pule Hill. The characteristic fauna of the bullions and limestones comprises

Cœlonautilus quadratus.
Orthoceras Steinhaueri.
Glyphioceras reticulatum.
Gl. bilingue.
Gl. diadema.
Gastrioceras Listeri.
G. carbonarium.
Bellerophon Urei.
Macrocheilina Gibsoni.
M. reticulata.
Nuculana stilla.
Schizodus antiquus.
Sanguinolites tricostatus.
Posidoniella lævis.
Aviculopecten papyraceus.
A. fibrillosus (?).
Rhizodopsis sp.
Strepsodus sauroides.
Elonichthys Aitkeni.

[1] Trans. Manch. Geol. Soc. vol. xxiv (1896) p. 70.

The Calder Valley gives exposures of the Pendleside Beds near Todmorden, and in Crimsworth Dean and Horsebridge Clough, north of Hebden Bridge. Continuous sections from the grits downward are to be seen in the streams which flow through these pretty little gorges. For many years collectors have found these localities very rich in fossil-remains, and a large and interesting fauna has been discovered here. Many of the specimens collected by Mr. Gibson are in the Manchester Museum, Owens College, and were described by Capt. Thomas Brown.[1] An idea of the richness of the fauna may be formed from the following list:—

The cephalopods included therein have been identified by Mr. G. C. Crick (see Cat. Foss. Cephalopoda, Brit. Mus. Nat. Hist. pt. iii, 1897). Capt. Brown listed twenty-six species of goniatites.

Glyphioceras Phillipsii.	*Dimorphoceras discrepans.*
Gl. vesica.	*D. Gilbertsoni.*
Gl. implicatum.	*Gastrioceras carbonarium.*
Gl. reticulatum.	*G. Listeri.*
Gl. Davisi.	*Nomismoceras spirorbis.*
Gl. diadema.	*Orthoceras* cf. *Morrisianum*, de Kon.
Gl. calyx.	*O. Steinhaueri.*
Gl. stenolobum (?).	*O. annulatum.*
Gl. platylobum.	*Cœlonautilus bicarinatus.*
Gl. nitidum (said to come from Todmorden: history unknown).	

(Capt. Brown figured four species of *Orthoceras*. Davis enumerates fourteen, most of which are undescribed.)

GASTEROPODA.—Capt. Brown described nine species of spiral shells referred to five genera. Mr. Davis later on listed twenty-three, the majority of which were fortunately *nomina nuda*.

This order has been neglected, but we have ourselves only found three species, probably referable to *Macrocheilina*, the *Buccinum elegans*, *B. Gibsoni*, and *Pyramis reticulatus* of Brown.

LAMELLIBRANCHIATA.

Aviculopecten papyraceus.	*Posidoniella variabilis.*
A. Samuelsii [? = young of *A. papyraceus*].	*Schizodus antiquus.*
Posidoniella lævis.	*Sanguinolites tricostatus.*
P. Kirkmani	*Nucula æqualis.*
P. minor.	*Leiopteria longirostris.*

Davis enumerates twenty-eight species, the majority of which are, however, *nomina nuda*. Capt. Brown figured and described fourteen species, several of which are synonyms.

One or two brachiopods are said to occur, referred to species which are found at various horizons both above and below the Pendleside Group.

The total absence of corals and protozoa is to be remarked. Crinoids are rare, fragmentary, and very small.

PISCES.

Orodus sp., tooth.	*Acrolepis*, scales.
Cladodus sp., tooth.	*Elonichthys Aitkeni.*

A few plant-remains occur in the group.

[1] Trans. Manch. Geol. Soc. vol. i (1841) p. 212. In this paper some forty-four species were described and figured: several of the species are synonyms, and many of the types have disappeared.

The late Mr. James Spencer, of Halifax, collected carefully from the beds passed through in tunnelling under Wadsworth Moor for the Halifax Water Scheme. He obtained a very extensive marine fauna, practically identical with that found at Horsebridge Clough and Crimsworth Dean, but considered that the horizon was somewhat higher, placing the chief marine bed in the D shales, above the Kinderscout or Fourth Grit. We have obtained possession of this extensive collection, and the identity of the fauna with that occurring at Horsebridge Clough and Marsden is very striking. Mr. Spencer's fossil-lists are published[1]; the nomenclature of the fossils is somewhat redundant, owing to the fact that many species therein mentioned are synonyms. At Eccup, near Leeds, an extensive marine fauna is found in shale between the Third and Fourth Grits: the fauna, however, is richer than that of Horsebridge Clough, containing a few more lamellibranchs.

The Carboniferous Sequence in the Isle of Man.

Three distinct series can be made out to exist in the Carboniferous Beds in the south of the Isle of Man, but the relations of the shell-mounds and the *Posidonomya*-beds of Poolvash are obscured by lateral movements and interbedded ashes and volcanic rocks.

Mr. Lamplugh has worked out the details, which he is now publishing, so little need be said here beyond showing that the three members of the series are characterized by different faunas, and pointing out the similarity of the fauna of the Poolvash limestones and their close resemblance in lithological character to the vaguely-stratified, white, crystalline, highly fossiliferous beds of Cracoe, Castleton, Thorpe Cloud, and Park Hill. (See Appendix A, facing p. 402.) The succession is as follows, in descending order:—

1. Black calcareous shales with black limestones. *Posidonomya Becheri*, *Solenomya costellata*, *Orthoceras sulcatum*.
2. Masses of shelly white limestones with *Productus giganteus*; and a very rich fauna of typical Carboniferous-Limestone species.
3. Hard blue well-stratified limestones of Scarlett and Ballasalla, with *Prolecanites compressus*, *Edmondia sulcata*, *Allorisma monensis*; and large corals—*Cyathophyllum fragile*, *Zaphrentis cylindrica*.
4. Basal conglomerate.

It is evident that in the Isle of Man, the shales between the *Posidonomya*-schists and the shelly limestone have thinned out and disappeared; and it is probable that the *Posidonomya*-beds and black limestone are the equivalents of the Pendleside Limestone Group. The Rev. J. G. Cumming described several species of *Goniatites* and *Orthoceras* from these beds, and stated that these fossils occurred

[1] Proc. Yorks Geol. & Polyt. Soc. n. s. vol. xiii (1898) pp. 391–94.

plentifully in a bed of shale belonging to the Posidonian schist-series in

'soft shale charged largely with sulphuret of iron, and in this we have preserved (converted into that sulphuret) the remains chiefly of cephalopods, *Goniatites*, and Orthocerata.' [1]

Position of the *Posidonomya*-Schists in Ireland.

Beds classed as Upper Limestone Shales are found in County Dublin, and are exposed in the brooks of the Westown Demesne. The fauna found in this series is tabulated as follows in the Memoir of the Geological Survey of Ireland, Expl. Sheets 102 & 112 (1861), p. 60:—

Aviculopecten papyraceus.	*Goniatites crenistria* [*Gl. spirale*].
A. variabilis.	*G. Listeri.*
Posidonomya membranacea.	*Orthoceras* [*Steinhaueri*].
Lunulicardium [*Footii*].	*Dithyrocaris* sp.

In the list of fossils *Posidonomya Becheri* is stated to be very common in the Upper Limestone Shales at several localities.

We have had the opportunity of examining the goniatites from this locality, and are of opinion that those labelled *Goniatites crenistria* should be more correctly referred to *Glyphioceras spirale*. *Prolecanites* sp. and *Nomismoceras* sp. also occur on the same slabs. Further, some of the specimens labelled *Posidonomya membranacea* seem to us to be large examples of *Posidoniella lævis*. The fauna is therefore completely characteristic of the Pendleside Group.

The fauna of certain beds on Foynes Island, supposed to be Lower Carboniferous, is interesting, and includes the following:—

Posidonomya Becheri.	*Glyphioceras reticulatum.*
Aviculopecten papyraceus.	*Gastrioceras Listeri* (?).
Orthoceras minimum, Baily.	*Nautilus tuberculatus.*

Two gasteropods named by Baily (*Loxonema Galvani* and *Macrocheilus inflatus*) we consider to be identical with Thomas Brown's shells from Hebden Bridge (see p. 373), *Macrocheilina Gibsoni* and *M. elegans*.

The section given by the officers of the Geological Survey, Explan. of Sheet 142 (1860), p. 8, shows the beds, supposed to be Lower Coal-Measure, resting conformably and immediately upon the Upper Limestone Series. They may, therefore, very well represent the Upper Limestone-Shales or Pendleside Group, instead of Lower Coal-Measures. The characteristic fauna found in them affords strong presumptive evidence of this view.

Summary of the Stratigraphical Evidence.

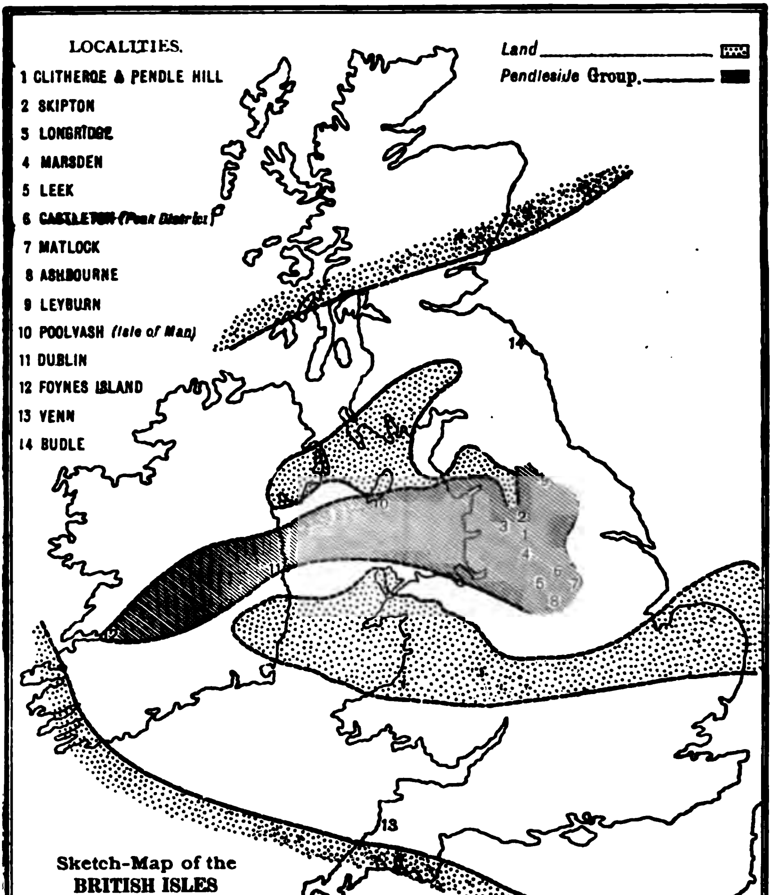
We have shown by detailed sections that a group of beds, characterized by a definite fauna totally different from that of the Mountain Limestone, exists in the form of a basin rapidly attenuating till they finally cease, along a line drawn from the Isle of Man to Harrogate. These beds have their maximum development in

[1] 'The Isle of Man' 1848, p. 133.

the country between Pendle Hill and Castleton, but north, south, and west of these points the beds rapidly thin out.

In lithological and palæontological characters these beds are

Fig. 1.



entirely different from the Yoredale Series of Wensleydale, and are altogether above it, for the strongest palæontological and stratigraphical evidence shows that the Yoredale Series of Wensleydale is the homotaxial equivalent of the upper portion of the Carboniferous Limestone massif.

There is consequently a well-marked stratigraphical and palæontological break in the Carboniferous succession, which comes on in Scotland at the top of the Upper Carboniferous Limestone Series, in Northumberland and Northern Yorkshire at the top of the Yoredale Series, in Southern Yorkshire and Derbyshire at the top of the Carboniferous Limestone massif.

Palæontology shows that for purposes of classification a twofold division of the Carboniferous rocks obtains: one fauna with subfaunas characterizing the lower series, and another being characteristic of the Pendleside Group, Millstone-Grit Series, and Lower Coal-Measures.

The Pendleside Group consists of shales and limestones, with occasional sandstones and mudstones. The limestones are peculiar in character and form, and can never, even in small specimens, be mistaken for the white limestone of the massif. These limestones are largely lenticular, the limestones being very local; sometimes well-bedded limestones gradually pass into calcareous shales, or into shales with bullions of calcareous matter. Fossils are most plentiful in those localities where the limestones are thin and concretionary. Chemical and physical facts in connection with these limestones will be dealt with in another section, but the immense quantity of carbonaceous matter and hydrocarbons in the shales and also in the limestones is to be noted. The shales indeed are black with coaly particles and detrital plant-remains. These particles must have come from either terrestrial or marine plants, and in both cases indicate proximity to a shore.

The further facts of the distribution of *Glyphioceras spirale* and *Posidonomya Becheri*, set forth in the foregoing pages, open up the wide question of the age of the Culm-beds of Devon and Germany; and in reference to this point the discovery of radiolaria in the limestones of the Pendleside Group by one of us is important.

III. Palæontology.

In the Carboniferous-Limestone areas of Staffordshire, Derbyshire, Southern and Eastern Lancashire, and South-western Yorkshire, there exist two distinct faunas: one, the lower, is found in the Carboniferous Limestone, while the other characterizes the Upper Limestone-Shales, the marine bands of the Millstone-Grit Series, and the Lower Coal-Measures.

The basement-line of the upper fauna is the junction of the massive limestone with the dark shales which succeed it. At certain localities, Tissington in Derbyshire, Pendle Hill and Downham in Lancashire, at Park Head Quarry (Lothersdale) and Poolvash (Isle of Man), the abrupt change in the fauna may be seen; but in many other places, where the lithological change, which accompanies the palæontological one, is clearly visible, no fossils have been obtained by us at the actual junction. Thus at the London & North-western Railway-cutting north of Doveholes, the two series are seen in contact; yet no fossils are noticed in the

first few feet of the Shales, although they are present in large numbers some 30 feet above the base of the Shales.

A few species of brachiopoda—*Orthis resupinata*, *Athyris ambigua*, *Spirifera glabra*, *Sp. bisulcata*, *Productus semireticulatus*, *Pr. Cora*, *Pr. longispinus*, *Pr. punctatus*, *Pr. scabriculus*, *Discina nitida*, and a species of *Rhynchonella*—do certainly pass up from the lower series, and occur, generally rather dwarfed, at one or two horizons in the upper. Of lamellibranchs, *Edmondia unioniformis*, *Myalina Flemingii*, *M. Verneuilii*, and a few other species also pass up. The goniatite, *Glyphioceras crenistria*, said to be common to both series, has never been found by us to pass up. It occurs in lists of Pendleside fossils, but we have never yet seen it in these beds ourselves, and think it very probable that an error of determination has occurred.

The upper fauna is characterized by a number of peculiar aviculoid and mytiloid forms, referred to *Posidonomya* and *Posidoniella*, and some species of *Aviculopecten*; also by numerous cephalopoda—*Glyphioceras reticulatum*, *Gl. spirale*, *Gl. bilingue*, *Gl. diadema*, *Gastrioceras carbonarium*, and *G. Listeri*.

In the districts mentioned above, the cessation of the lower fauna as a whole, at the limit which we have indicated, is abrupt and final; and even where pure limestones occasionally appear in the shales, there is no reappearance of the lower limestone-fauna. On the other hand, in the series of limestones, shales, and sandstones of Wensleydale, a recurrence of similar lithological characters is attended by a repetition of the limestone-frequenting fossils. Speaking generally, the fauna of the Lower Scar Limestone and that of the Yoredale Series of Wensleydale is one and the same; although, as might naturally be expected, certain forms occur in the shales which may be altogether absent from the limestones. This, however, is due to bathymetrical distribution and to the conditions indicated by the nature of the deposit, certain species preferring muddy and others clearer sea-bottoms.

Moreover, the life-assemblage of the Great Scar Limestone and the true Yoredales is identical with that of the massive limestone of the southern type of rocks; but in individuals and species the latter is much richer than the former.

At present, in the area of the northern type of Carboniferous rocks, no indication has yet been found of a fauna between the Millstone Grit and the Yoredale Limestones at all equivalent to that in the Upper Limestone-Shales (Pendleside Group) of the southern area. The fauna of the alternating shale and limestone of the northern type has a close affinity with those of the Upper and Lower Limestone Series of Scotland, where the shales and limestones each possess fossils respectively peculiar to one or the other, but certain species are common and give an uniform facies to the whole. The large brachiopoda and corals are often absent from the shales; lamellibranchiata and small gasteropoda are more common in them. *Lingula* and *Discina*, *Orthis Michelini* and *Chonetes Laguessiana* seem to have been the chief brachiopods that preferred a muddy environment.

The massive limestones of the southern area are much richer in their uppermost beds. It is possible that metasomatic changes in the lower beds may have obliterated many fossils, or that the conditions attending their formation were unsuited to molluscan life. So far as our observations have gone, we are unable to say that any part of the great mass is characterized by the presence of sub-zonal forms, or that the lower beds ever contained a rich assemblage of individuals.

In comparing the life of the Carboniferous Limestone with that of the strata immediately above it, the great importance of corals as rock-builders in the former cannot be overlooked. Indeed, much of the limestone, now almost destitute of direct evidence of organisms, may have originated in this way: examination of recent coral-island material certainly goes far towards confirming this view. It is seldom that individual masses of coral measuring more than 108 ($6 \times 6 \times 3$) cubic feet can be found *in situ*, but in places they are present in such abundance and over such large areas that they must have formed considerable reefs. Even a simple coral, *Zaphrentis cylindrica*, for example, occurs at Knocklane Point (Serpent Rock), 2½ miles north-west of Grange in County Sligo, in such enormous numbers as to constitute an extensive deposit. In the Derbyshire limestone corals are plentiful at many horizons, but particularly in the upper 50 feet; thus, from the top of Masson Hill towards Winster a well-marked coral-deposit is traced for a distance of over 3 miles. They are common also in the Yoredale Limestones of Wensleydale; but in the Pendleside Group they are chiefly noticeable by their absence, only a few Zaphrentoid forms being known, of which *Z. Enniskilleni* is the most abundant.

The most important fact in the faunal distribution of the Pendleside Limestone Group is the association in these rocks of *Posidonomya Becheri*, *P. membranacea*, *Glyphioceras spirale*, *Gl. reticulatum*, *Posidoniella lævis*, and *Aviculopecten papyraceus*. Hitherto *Gl. spirale* was known only from the Culm Measures of Venn, near Barnstaple, and the Culm of Herborn in Nassau.

Posidonomya Becheri appears to have come in at a slightly earlier period than its associates, for it is found not only in the black beds, as at Budle (Northumberland), and the shales in connection with the Gayle and Hardraw Scar Limestone of Wensleydale, but specimens have been taken from white shelly limestone at Castleton (Derbyshire). This constant appearance of *P. Becheri*, *Glyphioceras reticulatum*, and often *Gl. spirale*, either singly or together, is not merely a local phenomenon, but is found to be the rule in Yorkshire, Lancashire, Derbyshire, Cheshire, and Ireland. *P. Becheri* seems to be restricted vertically to the lower portion of the Pendleside Group, but its associates, *Posidoniella lævis*, *Aviculopecten papyraceus*, *Gastrioceras Listeri*, *G. carbonarium*, *Glyphioceras bilingue*, *Gl. reticulatum*, *Nomismoceras ornatum*, and *Dimorphoceras Gilbertsoni*, occur again and again. They seem, however, to become extinct with the Middle Coal-Measures, in which they only appear in one or two widely-separated bands. Thus there seems to be evidence for a distinct

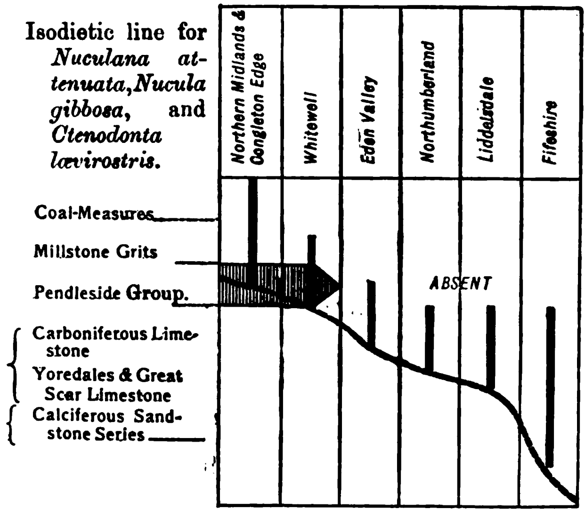
sub-zone in the lower part of the larger zone of *Posidoniella lævis* and *Aviculopecten papyraceus*.

The vertical distribution of the Pendleside fauna shows that the generally accepted subdivision of the Upper Carboniferous beds had no palæontological basis, and that on these grounds it is impossible to separate the Pendleside Group, Millstone Grits, and Lower Coal-Measures one from the other; such a subdivision is purely lithological and local. Some species of this fauna are even found at one or two horizons in the Middle Coal-Measures: as, for example, *Ctenodonta lævirostris*, *Aviculopecten papyraceus*, and others, in the North Staffordshire Coalfield, and near Ashton-under-Lyne.

While working at a Monograph of British Carboniferous Lamellibranchs, one of us found that the peculiar distribution of certain genera and species at widely different horizons in different areas was very striking. As evidence accumulated, it became certain that this distribution depended on similarity of conditions of deposition. It seems to us that by taking some fossil, or group of fossils, whose habits can be compared with some living representatives, and ascertaining at what horizons they occur in different localities, it may be possible to construct isobathymetric lines in the series of rocks or, at least, to draw lines in them connecting points of similar conditions of deposition; such lines we propose to call isodictic. As an example, we may take the Nuculidæ, a family which is represented in Carboniferous times by the genera *Nuculana*, *Nucula*, and *Ctenodonta*. The habits of recent members of this family and the depths at which they live are well known; S. P. Woodward gives the distribution of *Nucula* at from 5 to 100 fathoms.

The following tabular diagram (fig. 2) shows the isodietic line for

Fig. 2.



three species, *Nuculana attenuata*, *Nucula gibbosa*, and *Ctenodonta lævirostris*, but it seems that *N. attenuata* always came in some little time before the others.

The three genera mentioned above all appear in the Calciferous Sandstone Series of Scotland, and reappear in that area at many horizons in the Carboniferous Series up to the top of that subdivision.

According to Mr. J. W. Kirkby's tables[1] *Nuculana* (*Leda*) *attenuata* is found 3000 to 3800 feet below the Carboniferous Limestone, at a lower horizon than *Nucula gibbosa*, which comes in from 500 to 2300 feet below that bed. *Ctenodonta lævirostris* is not mentioned by him, and we have been unable to give the exact point at which it first comes in, but in the upper part of the Calciferous Sandstone Series of Fife all these fossils are found together. They never occur in the pure white or grey limestones, only in the shales between them.

In the West of Scotland these species are well represented in the shales of the Carboniferous Limestone Series. Mr. J. Smith, of Kilwinning, informs us that they have not been found below the 'shale' under the lowest 'post' of the Lower Limestone Series.

The Calciferous Sandstone Series in Eskdale, however, does not seem to possess these species, though they all come in in the shales associated with the limestones on the horizon of the Hurlet Limestone. Farther south, in Northumberland, *Nuculana attenuata*, *Nucula gibbosa*, and *Ctenodonta lævirostris* are absent in the Tuedian Series; *N. attenuata* comes on alone in the Carbonaceous division, but *N. gibbosa* is found with it in the shales of the Calcareous division above, at several horizons.

Still farther south, the lowest horizon at which we have been able to obtain *Nuculana attenuata* and *Ctenodonta lævirostris* in the valley of the Eden, is in shales presumably above the Underset Limestone. They probably do occur somewhat lower, however, for we have obtained *Ctenodonta lævirostris* in shales below the Hardraw Scar Limestone, although at present *Nuculana attenuata* and *Nucula gibbosa* are not known so low down in this locality. Farther south again, in beds presumably immediately above the main mass of limestone at Whitewell, *Nuculana attenuata* and *Ctenodonta lævirostris* appear, the latter being found at more than one horizon in the Pendleside Group.

Continuing in a southerly direction, we find in the Marsden Valley, at Eccup near Leeds, and Congleton Edge (Cheshire), the lowest horizon for *Nucula gibbosa* and *Ctenodonta lævirostris* in the upper part of the Pendleside Group and Shales below the Third Grit; while these shells are found at one or more horizons in the Coal-Measures of Lancashire and North Staffordshire. *Nuculana attenuata* has disappeared, but its place has been taken by *Nuculana stilla*.

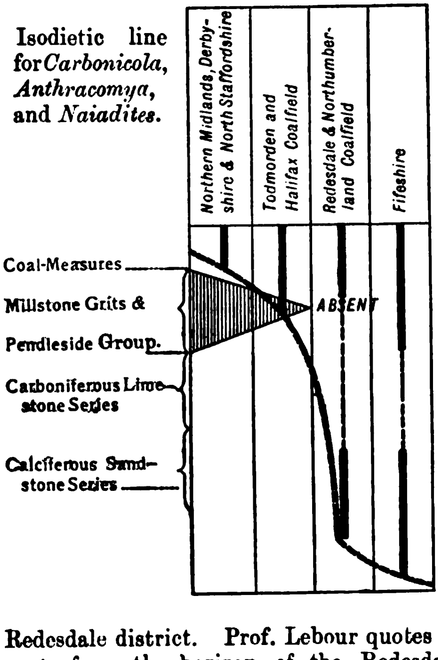
This peculiar distribution of allied forms of shells is very striking, and seems to us to point conclusively to the fact that the

[1] Quart. Journ. Geol. Soc. vol. xxxvi (1880) p. 589.

necessary conditions of deposition and environment for the members of the family Nuculidæ did not exist in the south till late on in Carboniferous times, and that the line drawn obliquely across the strata from the lower part of the Calciferous Sandstone Series to the Millstone Grits of the Midlands, represents an isodietic line for this family, which is exact for the individual species representing them. It will be seen that similar lines which have an almost identical curve can be constructed for other groups. Details of two groups are given in figs. 2 & 3: one group consisting of the Nuculidæ, the other of those genera—*Carbonicola*, *Anthracomya*, *Naiadites*—which, from the peculiar erosion of the umbones, are justly considered to have been freshwater dwellers: *Naiadites*, belonging to a byssiferous group, is chosen because in this case migration was limited naturally by structure and habit.

The genera *Carbonicola* and *Anthracomya* belonging to the Unionidæ, and *Naiadites*—a byssiferous genus belonging to the Mytilidæ, —have long been recognized as characteristic of the freshwater beds of the Coal-Measures, and have a wide horizontal distribution. An examination of the distribution of these genera during Carboniferous times gives an interesting result. All three genera are represented in the oldest Carboniferous rocks of Fifeshire: *Carbonicola* by two species, *C. antiqua* and *C. elegans*; *Anthracomya* by *A. scotica* and another well-developed form closely allied to, if not identical with, *A. Adamsii*; and *Naiadites* by *N. crassa* and *N. obesa*.

Fig. 3.



Isodietic line for *Carbonicola*, *Anthracomya*, and *Naiadites*.

These genera are, with the exception of *N. crassa*, absent from the Tuedian Series of Northumberland; but that species occurs in shales in the Carbonaceous and Fell-Sandstone Series at Lewisburn, and a species of the same genus (possibly a dwarf example of *N. crassa*) is found at Sillsburn in the Redesdale district. Prof. Lebour quotes *Anthracosia* (*Carbonicola*) *acuta* from the horizon of the Redesdale Ironstones, but after

examination of the specimen we are not able to recognize that it belongs to that genus.

Farther south, in the Yorkshire dales, the three genera have not been found either in the Great Scar or in the Yoredale Series. In the Pendleside Group, Messrs. J. Barnes & W. F. Holroyd have found three species of *Carbonicola* and one of *Naiadites* in rocks, presumably of this horizon, at Pule Hill Tunnel, near Marsden.

Still farther south, in Staffordshire and Derbyshire, these genera only come in at the base of the Coal-Measures, but they are each represented by numerous species.

If the horizons, at which a large number of the marine fossils of the Calciferous Sandstone Series of Fife occur in other districts, were noted, similar isodietic lines would be shown. In the case of the lamellibranchs, which we have chosen for the investigation (1) because they are now fairly well known; (2) because we were able to distinguish the species with some approach to accuracy; and (3) because in the adult stage they do not possess active means of migration, the isodietic line for the whole lamellibranch fauna of the Calciferous Sandstone Series lies within very narrow limits. It is practically identical with that of the Nuculidæ: that is to say, as one passes southward, a large part of the fauna of the Calciferous Sandstone Series occurs at continuously higher horizons, showing the gradual southward spread of similar conditions of environment. Many of the lamellibranchs of the Calciferous Sandstone Series preferring muddy and turbid waters, evidently could not live in the clear waters where limestones were accumulating. Thus it may be inferred that as Carboniferous times went on, the influence of the land was felt farther and ever farther south, as is shown by the tendency to interruption of the deposition of limestone by detrital shales and sandstones, and eventually the complete cessation of the formation of pure limestones, even in the area of maximum deposition.

With regard to *Aviculopecten papyraceus*, which we have chosen as a zonal form, it is interesting to note that it occurs at a lower horizon in Scotland than it does in England.

It is found in shale at East Kilbride, 2½ feet above the Calderwood Cement-Stone at Glebe Quarry, which is supposed to belong to the Lower Limestone Series of Scotland; but it seems possible that the beds really belong to the Upper Limestone Series, for lithological and palæontological reasons. In Northumberland this species does not seem to go below the base of the Coal-Measures, but it occurs in the Pendleside Group and passes up to the Coal-Measures in the Northern Midlands.

Chonetes Laguessiana appears to be an important species, on account of its almost universal occurrence in the Pendleside Limestone localities. It occurs in large quantities in Scotland, round Beith, in the Shales of the Lower Limestone Series. In the Yorkshire dales it occurs in the shales between the various Yoredale

limestones, but has not been found in the Great Scar Limestone below. In the area where the southern rock-types are found it is absent in the great mass of limestone, but occurs in the Pendleside Shales, and at one or two horizons in the Coal-Measures of North Staffordshire.

The byssiferous and always marine genus *Myalina* is represented in the Calciferous Sandstone Series by *M. sublamellosa*, *M. Flemingi*, *M. Verneuilii*, and *M. lamellosa*. In Northumberland this genus comes in the Carbonaceous division, in Northern Yorkshire it is found in the middle of the Yoredale Series, in Southern Yorkshire in the Millstone-Grit Series, and in Derbyshire in the top-beds of the Limestone, while in Cheshire it occurs in the Pendleside Group of Congleton Edge.

Isodietic curves similar to those above described could be traced for *Edmondia unioniformis*, *E. rudis*, *E. sulcata*, *E. M'Coyii*, *E. laminata*, and *E. scalaris*; *Parallelodon bistriatus* and *P. semicostatus*; *Protoschizodus axiniformis*; *Sanguinolites angustatus*, *S. striatolamellosus*, and *S. plicatus*; *Allorisma maxima*, *A. sulcata*, and others.

These isodietic curves, it will be observed, cut the zonal lines obliquely and in no way run parallel to them; and this must necessarily always be so, for as the littoral beds of a slowly sinking or rising area advance or retreat, migration of faunas must take place along lines which intersect the other life-zones at different horizons. Isodietic lines, therefore, in no way indicate time, but simply physiographical conditions, and in this sense are also life-zones.

It is to be seen from the fossil-lists in Appendices A & B (facing p. 402) that some few of the brachiopoda could accommodate themselves to an altered environment, but that at the same time the restriction of certain well-marked species to certain horizontal zones is very definite.

These tables clearly demonstrate that a similar set of conditions slowly passed along from north to south. Either the depth of the sea was shallowed by the accumulation of sediments to such an extent that sublittoral and byssiferous species found in it their necessary environment, or the sea was shallowed by elevation of the bottom: most probably the former. During the deposition of the Calciferous Sandstone Series in Fife, estimated as 3800 feet thick, marine limestones (averaging only about 50 feet) were laid down, containing practically the same faunas at several different horizons, and demonstrating that the amount of sedimentation was about equal to the amount of depression. The overlying series (the Carboniferous Limestone Series of Fife) comprises a much larger number of marine beds, and contains pure limestones of considerable thickness, showing temporary absences of detrital

sedimentation for a time. Such a condition, however, does not necessarily point to considerable or violent oscillation of the sea-bottom, for without any great alteration of depth, any circumstance such as a bar, or a change in the direction of currents, which would limit the area over which land-detritus was spread, would determine equally well the accumulation of limestones in new localities.

An analysis of the splendidly-compiled lists of the fauna of the Carboniferous Series of Fife, by Mr. B. N. Peach,[1] demonstrates some interesting facts as to the distribution of species in the Calciferous Sandstone and Carboniferous Limestone Series.

With regard to the plants, out of seventy-five named forms twenty-five are found only in the Calciferous Sandstone Series, and seven only (four of which have not received specific names) are common to the Calciferous Sandstone and Carboniferous Limestone Series.

The foraminifera seem to be common to both series.

No porifera or hydrozoa have been recognized in the lower series; and out of thirty-nine species of corals only four occur in the Calciferous Sandstone Series, two of which are not determined specifically.

Of echinodermata eleven species are enumerated: one form, *Hydreionocrinus globularis*, is common to both series, in which also crinoid-ossicles (undetermined) are stated to occur.

Passing on to the arthropoda, which are numerously represented, we find that the majority of forms occur at more than one horizon.

Of polyzoa, represented by twenty-six named species, only six occur in the Calciferous Sandstone Series, and three of these are not named specifically.

No brachiopod is confined to the Calciferous Sandstone Series. Of sixty species which occur in the Carboniferous Limestone Series, twenty-four are common to it and the Calciferous Sandstone Series. *Productus giganteus* is not found in this series.

About 100 species of lamellibranchs are found in the Calciferous Sandstone and Carboniferous Limestone Series of Fife, of which *Modiola Macadamii*, *Lithodomus carbonarius*, *Myalina sublamellosa*, *Edmondia subplicata*, *Sanguinolites abdenensis*, *Schizodus pentlandicus*, *Naiadites obesa*, *Carbonicola antiqua*, *Anthracomya lævis*, and perhaps *Pecten subconoides* at present seem to be found only in the Calciferous Sandstone Series.

Fifty-six species of gasteropoda occur, of which it is questionable whether any are confined to the Calciferous Sandstone Series.

Of the twenty-four species of cephalopoda, only eight are found in the Calciferous Sandstone Series and none of them are confined to that subdivision.

Judging from the list, certain fish-remains appear to have been, at present, only found in the Calciferous Sandstone Series.

[1] 'Geology of Central & Western Fife & Kinross' Mem. Geol. Surv. Scotl. (1900) pp. 216–51.

The fauna of the Calciferous Sandstone Series, therefore, contains very few fossils distinct from the Carboniferous Limestone Series, but is much less rich in species. These beds may be, and probably are, in point of time contemporaneous with portion of the Carboniferous Limestone of the Midlands; but they represent beds deposited much closer in-shore and under totally different conditions, subject to rapid and frequent changes of sedimentation and depth. The cephalopoda (such useful indices of the Pendleside Group) are rare, and afford no evidence for the purpose of establishing zones in this series.

A class of fossils which affords strong evidence that the Yoredale Beds of Wensleydale are the equivalents of the upper part of the Clitheroe and Derbyshire Limestone, is that of the fishes. The late James W. Davis published [1] descriptions of numerous species from various Carboniferous Limestone localities. The fish-fauna of the Limestone Series as a whole is remarkably distinct from that found in the Upper Carboniferous beds, and it is interesting and important to note the number of forms common to the Red Beds of Leyburn (Wensleydale), the highest limestone of the Yoredale Series, which underlies the Millstone-Grit Series, and the upper part of the limestone of Derbyshire. The fine suite of fossils obtained from Bolt Edge Quarry, near Chapel-en-le-Frith, yields important evidence of this fact, for the quarry is in the uppermost bed of the limestone-massif, a bed which in North Staffordshire and Derbyshire is the best hunting-ground for fish-remains.

The localities given in James Davis's work are not accurate enough, as a rule, to permit of the construction of tables of the occurrence of fish-remains. Except with regard to the Leyburn localities, we are not told from which of the many limestones of the Yoredale Series the specimens labelled 'Richmond' were obtained.

Certain genera (*Orodus*, *Cladodus*) are represented in the Pendleside Group—genera which have on the whole a Lower Carboniferous facies; but the great change in the fish-fauna comes in along a line represented in Wensleydale by the Red Beds at the uppermost limit of the Yoredale Series, and in the Yorkshire-Derbyshire area by the uppermost bed of the limestone-massif.

The numerous fragmentary plant-remains found all through the Pendleside Group are a very striking feature. Goniatites, and especially the byssiferous lamellibranchs, are often found attached in numbers to small bits of stem. These fragments occur occasionally in the limestones, but more frequently in the shales and sandstones. When of any appreciable size, the outside of the specimen is coated with a thin layer of pure coal.

[1] Sci. Trans. Roy. Dublin Soc. ser. 2, vol. i, 'Foss. Fishes Carb. Limest. Ser. Gt. Brit.' pp. 327 *et seqq.*; also Geol. Mag. 1886, p. 148.

The late James Spencer gave the following list of plant-remains from Horse Bridge Clough:—

Lepidodendron.	*Calamites.*	And ferns in abundance.
Sigillaria.	*Dadoxylon.*	
Stigmaria.	*Artesia.*	

Messrs. J. Barnes & W. F. Holroyd also note from the same horizon at Marsden:—

Neuropteris sp.	*Lepidodendron.*	*Sigillaria.*
Sphenopteris sp.	*Calamites.*	*Lepidostrobus.*

Elsewhere, except at Congleton Edge Quarry below the marine bed, we have not been able to obtain plants sufficiently well preserved to be definitely named.

The following table (p. 388) of life-zones which is here suggested for the British Carboniferous rocks is constructed on broad lines, and some of the larger zones contain sub-zones which are merely indicated by the names of the zone-fossils. It will be seen that we are unable to establish sub-zones at present for the great zone of *Productus giganteus*. An examination of the table of fossils in Appendix A (facing p. 402) shows that at present no species has been found to be confined to any definite part of the Carboniferous Limestone Series. This was the conclusion arrived at by the late George Morton, who spent many years of careful work in the examination of, and collecting from, the various beds of the Carboniferous Limestone Series of North Wales.

The subdivision of the Carboniferous Series on palæontological grounds is not in accord with the generally accepted classification of the British Carboniferous rocks into Coal-Measures, Millstone Grits, Yoredale Shales, and Carboniferous Limestone Series. It is distinctly shown that the main palæontological divisions are twofold, with a secondary subdivision of each main group. With regard to the upper group, the separation of the Lower Coal-Measures from the Millstone Grits is not borne out, nor can the Pendleside Limestone Group be separated from the Millstone Grits; but the whole sequence is one well-marked series characterized by a very definite fauna, and the palæontological break only comes in at the base of the Middle Coal-Measures. Beds of coal are found at several horizons in the Millstone Grit Series, and even in some few localities in the Pendleside Group (Congleton Edge), though not of any economic value.

When the extremely local character of the Millstone Grits and the Pendleside Group is once recognized, it will be evident that the stratigraphical lines of the older classification cannot be carried over any extent of country, and hence the peculiar mistake which placed the Yoredale Series of Wensleydale as the equivalents of the Pendleside Group. Would any geologist who was surveying Wales, Ireland, Scotland, or England north of the Tyne only, ever have

TABLE OF LIFE-ZONES SUGGESTED FOR THE BRITISH CARBONIFEROUS ROCKS.

	ZONES.	ENGLAND.	SCOTLAND.	IRELAND.	ISLE OF MAN.
UPPER COAL-MEASURES.	Zone of *Anthracomya calcifera.*	*Spirorbis*-limestones, Upper Coal-Measures.	Upper Coal-Measures of Ayrshire.	? Wanting.	Wanting.
	Zone of *Anthracomya Phillipsii.*	Upper Coal-Measures of Lancashire, Yorkshire, Staffordshire, and Bristol.	The Red Measures of Fifeshire.	? Wanting.	Wanting.
MIDDLE COAL-MEASURES.	Zone of *Naiadites modiolaris* and *Anthracomya modiolaris*: containing sub-zones of *Anthracomya Wardi*, *A. Adamsii*, and *A. Williamsoni*.	Middle Coal-Measures, universally.	Coal-Measures of Fifeshire.	Coal-Measures, Castlecomer and Leinster.	Wanting.
GANNISTER GROUP LOWER COAL-MEASURES. MILLSTONE GRITS. PENDLESIDE GROUP.	Zone of *Aviculopecten papyraceus*, *Gastrioceras Listeri*, *G. carbonarium*, *Glyphioceras reticulatum*, *Gl. bilingue*, *Posidoniella lævis*, *P. minor*, with a sub-zone near the base of *Posidonomya Becheri*.	Gannister Group of Lower Coal-Measures. Millstone Grit. Pendleside Group. ? The Culm Measures of Venn and Swimbridge.	? Wanting. *Aviculopecten papyraceus*, said to be found above the Ell Coal, Wishaw, and in the Lower Limestone Series of Kilbride.	? Coal-Measures of Foynes Island (County Limerick). Upper Limestone Shales, County Dublin and County Meath.	The *Posidonomya*-schists of Poolvash.
CARBONIFEROUS LIMESTONE SERIES.	Zone of *Productus giganteus*, *Pr. Cora*, *Chonetes papilionacea*, and *Amplexus coralloides*.	The Carboniferous Limestone of Derbyshire and Staffordshire. Measures from the Great Scar Limestone to the Main Limestone, N.W. Yorkshire. Carboniferous and Calciferous divisions of Northumberland. Carboniferous Limestones of North and South Wales and the Mendips.	Carboniferous Limestone Series (Upper, Middle, Lower) of both the East and West of Scotland and Roxburghshire.	The Upper Limestone. The Calp. The Lower Limestone.	The limestones of Poolvash, Scarlett, and Ballasalla.
	Zone of *Modiola Macadamii.*	The Lower Limestone Shales of the Mendips.	Calciferous Sandstone Series of Fifeshire, Haddingtonshire, and Eskdale.	The Coomhola and Moyola beds (Co. Tyrone); Co. Cork and Co. Down.	? Basement-conglomerate.

established a Millstone Grit Series if he had not thought it a sacred duty to make the succession of rocks in those areas conform to a typical section, the extremely local character of which had not been recognized? In North Staffordshire and Derbyshire it is absolutely impossible to establish a satisfactory stratigraphical base or top for the Millstone Grit Series, and North Staffordshire and Derbyshire are areas where the grits are strongly developed.

On the other hand, palæontology with no uncertain hand points out the main and secondary lines of subdivisions, and clears away all the stratigraphical difficulties which have heretofore hindered the correct correlation of the different types of Carboniferous rocks in Great Britain and Ireland.

IV. Physical Geography. (See map, fig. 1, p. 376.)

The peculiarly regular and gradual change from north to south in the character of the Lower Carboniferous rocks of Great Britain points clearly to a geographical factor: that factor is the close proximity to, and the influence of, land.

Despite the physiographical maps of this period published by Prof. Hull, the late Prof. Green, and Mr. Jukes-Browne, in which this proposition is distinctly laid down, the deductions from the facts on which these maps are based have not been used to elucidate the change in character of the Carboniferous rocks. On the one hand, contemporaneous faults of considerable throw, and on the other, subsequent highly complicated and extensive local movements, have been advanced to explain changes which are entirely due to alterations of depth and coast-line.

The maps just quoted all agree in placing a large continent to the north and east (which is the main factor), and a more or less continuous barrier of older rocks extending from Wicklow to Leicester; but they differ in many details, which are of no great importance and need not be discussed here. The central ridge, however, was practically of no great extent from north to south, and is unlikely to have furnished any very considerable amount of sedimentary material. Indeed, it is probable that here was a long line of high cliffs, and the deepest water of the Carboniferous sea in Britain was north of this elongated neck of land.

Practically no Carboniferous rocks are to be found north of a line joining the Firths of Tay and Clyde, and therefore somewhere along that parallel must have been the line of the old Carboniferous shore. The lithological character of the Calciferous Sandstone Series, its grits, its shales, with many freshwater genera at several horizons, and its only occasional marine bands, all point to such a condition—proximity to land. Sandstone and shale-deposits denote the wear and tear of land-surfaces, and demonstrate the fact that they were laid down within the fan-shaped area which received the solid matters brought down by any large river.

The whole of the Carboniferous Limestone Series of Scotland corresponds very closely with the alternating series of the Yoredale

beds lithologically and palæontologically. In addition, there is the interesting and pregnant fact that the upper and lower series are separated by an intermediate set of beds, in which are extensive seams of coal and ironstone, pointing to a closer proximity to land during their deposition than was the case with the beds immediately above or below them, and land itself, indeed, if it be admitted that coal grew in the place where it is found. The recurring series of sandstones, shales, and limestones point to three sets of conditions:—sandstones, a more rapid current or a position nearer the mouth of the river; shales, a slower current or a position farther from the river's mouth; limestone, a pure marine organic deposit in water uncontaminated with sediment, not necessarily any great distance from land, but out of reach of the solid matter brought down by rivers.

We know something of the old floor, which sank to receive the basement-beds of the Carboniferous Limestones in Ribblesdale and near Ingleton, and farther north near Shap and beneath Whitbarrow, and from the sharpness of the upturned edges of the Silurian slates we infer that these must have been dry land immediately before they sank beneath the waters of the Carboniferous Limestone sea. We may assume also, from the evidence of the country, that the older rocks of the Lake District were never submerged. It seems to us not improbable that a strip of country passing from the Lake District across the Isle of Man to the Mourne Mountains in Ireland formed a more or less continuous mass of land throughout Carboniferous times. Most of the Western Isles of Scotland and the Highlands were also unsubmerged. Here was the land, probably extending far to the north-east and north-west, which was the source of the sands and mud (sandstones and shales) of the Yoredale Series, brought down by rivers and spread out over the pear-shaped area occupied by the series of limestones, sandstones, and shales, comprising the northern type of Carboniferous rocks. At times when, by some means or other, either oscillations of the land, alteration of currents, or by the formation of reefs or bars, this detrital matter was prevented from being laid down in certain areas; or, owing to depression of the land, river-action was largely minimized, calcareous ooze was thus able to accumulate over much larger areas, and the fauna which inhabited the clear sea in the south found it possible to advance northward again and again, only to be annihilated or driven back by the recurrence of conditions unsuitable for its habits. The detrital matter brought down by a large river is spread out over a more or less pear-shaped area which extends from the mouth, some distance out to sea. Marine conditions largely obtain here, but mixed with the marine fauna of this area, plants and other organic bodies, brought down by the river, will be found. The ground occupied by the Yoredale Series forms the distal lobe of such an area, and therefore we find this series with a pure, thick, limestone-boundary to the west and south. Such a conception takes away all the difficulties in the way of explaining the occurrence of the two types

of Carboniferous rocks, and accounts for the apparently sudden character of the change.

As previously remarked, in the Barrow and Grange district the great mass of limestone is undivided; and on the east, along the line of the Nidd, and the eastern part of Wharfedale, the limestone is undivided for a considerable distance farther north than is the case between these limits. The influence of the high land of the Lake District in limiting the deposition of grits and shales in the Carboniferous area south and west is very apparent. Similarly the influence of the great east-and-west barrier of high land extending across Central Wales to Charnwood, and possibly even from the Wicklow Hills, prevented the deposition of the whole of the Lower Carboniferous rocks for some distance south of the Pennine basin.

Even as far south as Derbyshire a short series of passage-beds, shales and limestones, are found at the top of the limestone, showing that this area had then come within the limits of mud-laden water. Thus the Carboniferous Limestone Series of Scotland and the North of England, the Great Scar Limestone and the Yoredales, and the Carboniferous Limestone of Central England, that is to say, the whole Pennine system, tell all one story, and form a fairly complete epitome of the various synchronous deposits which may be laid down in waters close enough to land to be affected by rivers and currents, a view supported largely by palæontological evidence of the migration of species and genera, as shown in the tabular diagrams (figs. 2 & 3, pp. 380 & 382).

The Millstone Grit area of Great Britain is much more limited than might be supposed. The whole series forms a lenticular mass, with a maximum deposit in the district between Pendle Hill and Kinderscout.

As the series passes northward, southward, and westward, both the thickness and number of the beds diminish rapidly, but on the east the grits disappear beneath newer measures, and nothing can be stated about them. We know that the Grit Series is absent in the Isle of Man, the Barrow district, Leicestershire, Shropshire, and South Staffordshire, and is of little moment in North Wales, if it be really present there. It has always appeared to us that the beds in Scotland referred to the Millstone Grit are neither more nor less than Coal-Measure sandstones. In several places beds of coal are found between the Grits, especially in the area of their maximum deposition; and, although in the Midlands the Millstone Grit Series forms a well-marked subdivision, even in that area there is much uncertainty as to the base, for it is preceded by a series of thin sandstones. Moreover, thick quartzose sandstones occur in the Lower Coal-Measures, very difficult at times to distinguish from the beds mapped as Grits.

The area of maximum deposition of the Grits corresponds also to the area of maximum deposition of the Pendleside Limestone Group, which is even more limited in area than the Grit Series. The Grits overlap the Pendleside Group considerably to the north.

We have adduced stratigraphical evidence that, north and west of Pendle Hill, this series rapidly diminishes in thickness, till in the Isle of Man only a few feet of black shales and limestones represent the great thickness seen in Pendle. To the south also, in Staffordshire and Derbyshire, we have shown this series to have become much thinner. We know that the series is absent in Shropshire, South Staffordshire, North Wales, and probably Leicestershire. To the north, if represented at all, the beds are much thinner and not easily recognized.

The important fact to be noted in connection with the distribution of the Millstone Grits and the Pendleside Group is that the maximum area of deposition of both coincides with each other and with the area in which the limestone is thickest and undivided. That is to say, the British Carboniferous rocks were laid down in a basin, the greatest depth of which was approximately in the Northern Midlands.

Unfortunately the size of the grains and included pebbles in the various beds of the Millstone Grit is so variable and local that it does not permit of any definite conclusion as to their direction or source of origin, but the pebbles in the Kinderscout Grit do become larger as the beds pass eastward. The Calciferous Sandstone Period is the Carboniferous Sandstone or Grit age of Scotland and the North of England; the pre-Coal-Measure period represents the great deposit of detrital quartz in North Central England. Do these facts help us to determine anything as to the source whence the beds were derived? Although the granites of the Highlands of Scotland are a possible source of the Calciferous Sandstone Series, the Millstone Grit Series is certainly not connected with this district by beds which thicken as they pass northward, nor are the Grits coarser in that direction. A western source may certainly be negatived, for the beds all appear to die out to the west, and the same condition obtains southward.

The Carboniferous sequence in Belgium shows a thick mass of limestone separated from the Coal-Measures by only a very small group of beds, which contain the fauna of the Gannister Series. Evidently this area was altogether outside the region of grit-deposition. By a process of exclusion, therefore, the pebbles and quartz of the Millstone Grit Series could only have been derived from land lying to the east and north-east, probably from a continent which included the Highlands of Scotland and Scandinavia. The source of the Millstone Grits must have been largely a granite-area, for mica and felspar, the latter sometimes decomposed into a china-clay, are found abundantly in certain of the beds. The Pendleside Group probably was derived from the same direction, and was laid down farther from the shore than the Millstone Grit, and therefore the whole of the deposits indicate a slowly-rising area.

On the other hand, the migrations of faunas, the geographical situation of the beds, and the stratigraphical evidence point strongly to a more directly northern source for the shales and sand-

stones of the whole of the Lower Carboniferous rocks of the North of England, which therefore were the result of denudation by a different river-system from that of the Upper Carboniferous Series. If this be so, it is easy to understand why the Pendleside Group is limited to the north and does not occur between the Grits and the Yoredale Series, and to perceive the great factor which limited the distribution of the Pendleside Limestone Group to so definite and so comparatively small an area in Central England and Ireland.

The extent and comparative thicknesses of the Pendleside Group are shown in Pl. XIV; these were arrived at by estimating the thickness of the deposit wherever strictly reliable evidence could be obtained.

On the eastern side of the Derbyshire and Staffordshire anticline at Matlock the group is almost 400 feet thick; still farther north, in the neighbourhood of Eyam, the thickness is 300 to 350 feet, and presumably it is almost the same around Castleton, the thickness being calculated from the Pendle, Farey's, or the Yoredale Grit to the top of the massive limestone. Coming round to the western side of the anticline in the railway- and tramway-cutting north of Doveholes Station the beds are about 400 feet thick, but on the Cheshire side, where the Lower Millstone Grits are not so well developed, the whole series between the Third Grit and the limestone-massif is about 1000 to 1200 feet; deducting 500 to 600 feet as the representatives of the Kinderscout and Farey's Grit, it will be seen that the Pendleside Group is not very much thicker here than on the eastern side. This increase of thickness is explicable, and seems due to the fact that about 500 feet below the Third Grit on Congleton Edge a series of thick quartzose, gannister-like sandstones occur, which probably represent the Farey's Grit.

The Pendleside Group at Pendle may be estimated at 2300 feet, showing a great increase in thickness as compared with that which obtains in Derbyshire. Unfortunately, between Castleton and Clitheroe the limestone-massif is not exposed, consequently no base-line is available for calculating the thickness of the Group in the Calder Valley.

North of Pendle the beds rapidly thin out till at Thorpe, near Burnsall, the Group is only 450 feet thick.

Assuming an east-north-easterly or north-easterly direction for the source of the material, the axis of greatest thickness would lie obliquely from Pendle to Congleton, gradually thinning as it passed southward; but south and south-east, and north and north-west, of this axis, that is, towards the edges of the basin, the deposits would become much thinner, and they are so in fact.

V. Chemical Characters of the Pendleside Limestones.

Although it cannot be said that a few analyses of limestones gathered from isolated points over a wide area are of any value for stratigraphical purposes, yet the following chemical analyses, kindly

undertaken for us by Mr. R. F. Robinson, will assist in conveying an impression of the nature of the rocks under discussion.

Numbers	225	† 314	228	343	346	†† 226	† 316	† 319	* 227	* 187
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.
CaO	42·51	40·09	13·80	46·80	20·23	48·37	34·28	42·84	54·53	52·80
MgO	2·62	1·11	0·71	0·15	0·20	0·14	trace	0·59	0·11	trace
CO_2	38·94	31·96	11·19	36·75	16·50	38·20	31·24	36·69	43·08	41·67
SiO_2 & insoluble residue.	5·09	17·57	54·03	9·16	54·33	9·32	24·00	13·37	0·61	0·55
FeO	4·15	} 5·38	8·45	3·36	4·84	trace	} 8·22	4·57	trace	} 3·65
Al_2O_3	1·10					2·25			0·56	
Organic matter	4·48	3·16	10·45	3·76	2·88	1·07	1·90	1·59	0·34	0·44
Moisture	0·27	0·11	0·68	0·11	0·51	0·11	0·54	0·15	0·18	0·15
	99·16	99·38	99·31	100·09	99·49	99·46	100·18	99·80	99·41	99·26

* These rocks are from the 'Knoll Limestone.' † From Pendle Hill. †† A local phase of the Mountain Limestone. All the others are from the Pendleside Group.

225. A black limestone, from shales in the valley of the River Dane (North Staffordshire).
314. Dark limestone, from shales in stream at Hall Foot House, Worston (Lancashire).
228. Black, soft limestone, from shales at Cromford (Derbyshire).
343. Black limestone, from near the base of Stebden Hill (near Cracoe).
346. Muddy limestone, from shale at the south-eastern corner of the foot of Keal Hill, Thorpe (near Grassington).
226. 'Black Marble,' from Ashford (Derbyshire).
316. Hard, grey, siliceous limestone, from Pendle Hill (Lancashire).
319. Brownish limestone, with sponges, from Pendle Hill.
227. White limestone, from Hill Bolton, near Grassington.
187. White limestone, from Bunster Hill, Dove Dale (Staffordshire).

The first five rocks in the foregoing table are all black rocks, varying considerably in hardness and texture; the two hardest (Nos. 225 & 343) have a higher percentage of lime than the others, while the two softest (Nos. 228 & 346) yield the highest proportion of insoluble residue.

As might be expected, the amount of organic matter is higher in these black rocks than in any of the others, but varies both in its amount and nature. In No. 228 there is a good deal of volatile hydrocarbon present: this may be distilled off at a low temperature, leaving behind some bituminous substance which is expelled at a higher temperature. This rock is only a hardened phase of the black shales in which it occurs, and approaches an oil-shale in character.

All these black rocks exhibit in section minute fragments of vegetable origin, scattered throughout the mass, or lying along lines parallel to the stratification. Their dark colour is due in part to the presence of these vegetable fragments, but in addition, the granular calcite of which they are mainly composed is uniformly stained, the thin sections appearing yellow or brown, or being quite opaque and black.

Iron (in the condition of sulphide and oxides) is invariably present, and no doubt assists in the colouring of the rock, but it is interesting to note how small a percentage of either iron or carbonaceous matter is effective in producing the dark colour, for in

No. 226, which is the well-known Black Marble of Ashford (Derbyshire), from the Mountain Limestone Series, we find only a trace of iron and only 1·07 per cent. of organic matter. The black marble is a dark-grey, compact rock, weathering pale grey, but when polished, quite black.

From almost every part of the area described in this paper the limestones in the shales are of this black type alone: sometimes occurring as layers of black hard nodules, bullions, lying in the soft black shale, or as indurated portions of the shale itself, with a tendency to break up into shaly material on exposure to the weather; but on Pendle Hill itself, as we have already shown, rocks of various other types occur in addition to the black limestone; of these Nos. 316 & 319 are a fair illustration. No. 316 is the rock which assumes 'anvil'-forms on weathering, and No. 319 is the sponge-bearing rock described on p. 397. It will be seen that they are limestones with a fairly high percentage of silica.

None of the Pendleside rocks analysed show any appreciable amount of magnesia, but some of the beds, evidently the product of alteration of the above-mentioned limestones, are almost pure dolomites, and sections show the passage of one form into the other.

In the grey limestones, such as No. 316, chert appears in small patches, but beds of chert also occur from ½ inch to 18 inches thick at intervals among the limestone. There are two varieties, one black, homogeneous, and compact, and another grey and more porous in appearance.

One of the black, rather concretionary limestones from near the top of the limestone series on Pendle Hill, at the upper limit of the wood above Little Mearley Hall, weathers on the surface, possibly through the action of peaty water, into a layer of chocolate-brown soft material with a weakly developed cone-in-cone structure, appearing as small concentric circular depressions measuring about ·25 to ·5 inch in diameter. We have not obtained enough of this material for analysis, but on treatment with cold hydrochloric acid it readily breaks down, without effervescence, into a dark-brown syrup with an abundant residue of minute crystalline rods of silica, generally with flat terminations. These rods are about 1·4 mm. in length and from 0·3 to 0·4 mm. broad; they are probably broken sponge-spicules. The material is evidently a kind of rottenstone.

Nos. 227 & 187 are typical examples of the white limestone of Hill Bolton, Thorpe (near Grassington), and Bunster Hill, Dovedale, on the Staffordshire side of the river. We have analysed these samples, in order to show the very noteworthy difference in purity between the white limestone of the Mountain Limestone and even the purest in the Pendleside Group.

We desire particularly to contrast the analysis of No. 227 from Hill Bolton, one of the 'knoll-reefs' described by Mr. Tiddeman[1] with that of No. 346, which we understand, according to Mr. Tiddeman's view, to be a portion of the same rock which had rolled down

[1] Brit. Assoc. Rep. 1889 (Newcastle) p. 602.

from the 'knoll' and become embedded in the surrounding shales (see p. 362). No. 346 is from the foot of Keal Hill, and may be compared with No. 343 from a similar position near the foot of Stebden Hill, both hills being members of the series of Cracoe 'knolls.'

VI. Petrology and Micropalæontology.

The rocks of the Pendleside Limestone Group from the type-area on Pendle Hill, can hardly be said as a whole to exhibit characters of sufficient peculiarity to be of diagnostic value. This arises from the diversity of structure, composition, and origin among the members of the 'Limestone.' Indeed, to speak of the 'Pendleside Limestone,' as it is found on Pendle Hill, conveys an erroneous impression of an uniform and well-defined bed or series of beds, instead of which—as was pointed out by the officers of the Geological Survey[1]—we find banded mudstones, black limestones, magnesian limestones, grey limestones, more or less siliceous, and bands of chert. Of these only the black, rather impure beds are found in other districts, and such must be regarded as typical of the Pendleside Limestone Group; the others may be looked upon as a special local phase in this area of greatest development.

General Description of the Rocks in the Pendleside Limestone on Pendle Hill.

Hard Grey Limestones.

These limestones are best seen in the Clough above Hook Cliff, especially in the upper third of the limestone series. They are all organic in origin: crinoids, foraminifera, sponges, bryozoa and some hydrozoa, with occasional fragments of brachiopod-shells being associated together, sometimes one form, sometimes another preponderating. The organisms frequently appear to have been arranged in beds by the sorting action of gentle currents, for in some beds all the fragments are fairly large, in others they are all quite small: this applies to all the organisms alike. A laminated structure is evident in some of the beds, and is well brought out by weathering in the 'anvil-stones.'

A matrix of clear crystalline calcite is invariably present, and in many places in a thin section is seen to encroach upon and frequently obliterate the organisms.

Many interesting stages in the alteration of a simply organic into a crystalline calcareous or siliceous rock may be seen in slides cut from these limestones. The arenaceous structure of the walls of some of the foraminifera is generally well shown, their interior being filled with clear calcite. But frequently only the outline remains, enclosing a space of indistinct grey calcareous matter; *Archæodiscus*, as usual, retains its walls in a condition of amber-coloured clear

[1] 'Geology of the Burnley Coalfield' Mem. Geol. Surv. (1875) p. 17.

calcite longer than the other forms. Crinoid-fragments have seldom retained their original outline; in places the original calcite-cleavage remains, but more often this has been destroyed, and the only indication is the minute structure outlined in opaque grey material or in pyrites. Silicification on a small scale has taken place, in the form of irregular patches in the interior of crinoid-fragments.

Dolomitization may be traced from a few scattered rhombs and groups of crystals in a fairly pure limestone, through all gradations to a rock like the one from the old quarry in the wood above Little Mearley Hall, in which the process is complete and a true dolomite is formed, all indications of organic structure having been removed and only a thin dark line remaining to mark the boundary of the particles, and even this is often absent. Where the single rhombs are formed in the limestone they seem, as a rule, to commence on the margin of the organic body and grow towards its interior, entirely obliterating all structural details. It may be noted here that, where crystalline calcite has trespassed from the matrix into an organism, it is more common to find a trace of the original outline than when dolomite-crystals have behaved in the same way.

In the finer-grained beds, noticeably those with the 'anvil'-forms, the organic remains are less easily identified, and calcified sponge-spicules take a more prominent part. These spicules are mostly in the condition of clear calcite, with dark grey indistinct outlines. One of these sponge-bearing limestones, a compact, dark-grey to brown rock (No. 319), presents a very striking appearance, on account of the presence of small sponges, little patches $\frac{1}{8}$ to $\frac{1}{2}$ inch in diameter distributed over the lamination-planes (the lamination is probably determined by the sponges). The sponges are themselves in a siliceous condition, and as they appear whitish or yellow on the dark rock, they are fairly conspicuous. On treating lumps of this rock with cold hydrochloric acid an abundant residue of spicules and small silicified organisms remains. In the slide, however, this rock does not materially differ from the ordinary fine-grained limestone.

Cherts.

Associated with the limestones are two varieties of chert: one is a pale light-grey rock, weathering white; the other is black and compact, without any sign of organisms in the hand-specimen, but when sliced is seen to be a mass of ill-defined sponge-material. The two forms occur repeatedly in the upper part of the exposure, sometimes in the grey limestone and sometimes in the brown dolomitic beds.

The first-mentioned variety is undoubtedly a silicified representative of the grey limestones, and like them is found in several grades of texture. The coarse-grained chert is unlike any of the cherts that we have hitherto examined from the Mountain Limestone Series; it is extremely hard and breaks into cuboidal pieces. The organisms already mentioned as occurring in the grey limestones are easily distinguishable by the unaided eye. Examination of the weathered

surface with a lens reveals great numbers of minute rounded bodies (possibly foraminifera) with sponge-spicules, hydrozoa, and shell-particles; crinoidal débris seem less abundant than in the limestone. The matrix is a milky cryptocrystalline silica, transparent in section and colourless, but with occasional amber-coloured patches; in the less coarse forms there is less of the milky material and more of the amber-coloured silica. Most of the organisms are converted into the amber-coloured silica, but the internal casts are usually filled with a darker, more coffee-coloured material; in this way the structure of the foraminifera is occasionally very beautifully exhibited. Both the brown and the clear portions of the slide have the same appearance of cryptocrystalline silica when viewed in polarized light. In some of these cherts, the rounded bodies (mentioned above as visible on the weathered surface) are so crowded together that there is little room for matrix. Their most common form is roughly oval, with diameters of 0·32 and 0·24 mm., but some measure as much as $0{\cdot}6 \times 0{\cdot}32$ mm. Most of these bodies are foraminifera, the genus *Stacheia* being very strongly represented. On the whole, they show no internal structure nor wall, but stages can be seen in our slides showing every intermediate condition between foraminifera of the same size and general form, with perfect structure, through very indistinctly-marked specimens, to the rounded bodies devoid of all structural detail. Frequently a coarse hazy meshwork can be seen occupying the interior of the body, having a dark, dusty appearance in direct transmitted light, but appearing light-coloured by oblique illumination.

Fragments of irregular meshwork, sometimes clearly of sponge-origin, but more often doubtfully referred to those organisms, are to be seen here and there, composed of iron-oxide. In some of the slides, the dark-brown portions, whether in the casts of organisms or as irregular masses in the matrix, are marked by numerous small circles, generally isolated, but sometimes confluent. In size they are fairly uniform, ranging from 0·01 to 0·018 mm. in diameter. Their outline, except where they merge into adjoining circles, is very sharp, but no wall has been observed. They make their appearance in the casts of any of the organisms without discrimination.

These may be comparable with the bodies described by M. L. Cayeux as radiolaria and foraminifera,[1] but considered by Dr. G. J. Hinde,[2] who noticed something similar in the more cherty beds of the Devonshire Culm, to show no evidence of organic origin, and with this remark our own observations are in direct accord.

The rhombs of dolomite, noticed in the limestones, are also present in these cherts; they do not, however, retain their freshness, having apparently undergone some kind of alteration, and they are frequently surrounded and penetrated by dark iron-oxides. Minute rhombs in a fresher condition occur in the interior of some of the casts as well as in the groundmass. In some portions of the slides are

[1] Bull. Soc. géol. France, ser. 3, vol. xxii (1894) p. 197, & Comptes-rendus Acad. Sci. Paris, vol. cxviii (1894) p. 1433.
[2] Quart. Journ. Geol. Soc. vol. li (1895) pp. 631–32.

groups of exceedingly minute, highly refractive bodies of no very definite shape, but uniform in size, having a diameter of 0·001 mm.: they are most probably only an expression of the mineralization.

The finer-grained, light-coloured chert resembles in external appearance some of the cherts of the Mountain Limestone; in section it seems to represent the fine-grained grey limestone of Pendle.

Up to this point, if we except the coarse-grained chert, we have described no rock from the Pendleside Limestone which could not be exemplified in the Mountain Limestone. The richly foraminiferal limestones, for example, are exceedingly abundant in the darker upper beds of the massive Limestone Series, wherever they have been examined. Foraminifera are generally present, though not universally, and never so abundantly in the white limestones such as those of Clitheroe, Cracoe, Millersdale, Dovedale, etc. But at Chatburn, in the dark well-bedded limestones with thin shale-partings, below the white Clitheroe Limestone, they are again common, and in good preservation.

Again with regard to the dolomitized limestone, this, too, is found in great bulk in certain regions of the Mountain-Limestone area as an alteration-product of the latter, at Masson Hill, Matlock; Harbro' Rocks, near Brassington (Derbyshire), and elsewhere; but in this case it would nearly always be possible to discriminate between the two in hand-specimens. The Pendle rock is harder-looking, more crystalline and gritty in appearance than the other, and less suggestive of a 'dunstone,' the local name for the magnesian form of the Mountain Limestone in Derbyshire.

In the area that we have examined, we are not aware of any rock with sponge-patches resembling No. 319; but the grey fine-grained limestone with sponge-remains could be matched from many localities. One of the best sponge-limestones that we have yet found outside the Pendle rocks is a 3-foot bed near the base of Park Head Quarry, north of Lothersdale; it is wholly composed of spicules of calcite lying in a fine grey matrix.

There is, however, on Pendleside, at different horizons in the limestone series, a rock which we are disposed to regard as typical of the horizon of the Pendleside Limestone Group, that is, of the zone of *Posidonomya Becheri*, *Posidoniella lævis*, etc., not only on Pendle Hill itself, but in all other parts of the area over which we have traced the zone.

The Black Limestones.

These rocks are usually hard and black, very compact and close-grained, and exhibit a tendency to break with a subconchoidal fracture. Such is their condition at the base of the limestones at Hook Cliff, also at the top, and at intermediate points both above and below the grey limestones. The groundmass is fine granular calcite, stained brown; minute vegetable particles are nearly always visible in thin sections, and in the harder forms, sections of small goniatites and entomostraca.

When the limestones are found in the shales above or below the main development of the deposit, they are like the rocks just described, or are softer and possess a more banded structure. This banding is due to alternating layers of darker and lighter material, the individual layers frequently being extremely attenuated and very regular. In these softer rocks, thin streaks and layers of darkly-stained cryptocrystalline silica are common, so also are minute cubes of pyrites; no large organisms have been noticed in the slides, and the microscopic ones are in a very bad state of preservation. Indications of crinoid-stems and foraminifera are seen in some of the slides; always small, and generally indistinguishable, their size may be indicative of adverse physical conditions. The most prevalent organisms are sponges, represented by small fragments of spicules, so abundant in some of the black bands from the shales at the foot of the hill that they constitute the greater part of the rock. They are either formed of calcite or, more often, of the yellow silica.

The essential feature in the hard rocks is the presence of casts in clear calcite of small round bodies which are distributed throughout the rock, sometimes sparsely, but frequently in great profusion, and always standing out clearly against the dark background of the matrix. In no case have we yet been able to distinguish any internal structure that could be relied upon with certainty in allotting these bodies to their proper zoological position, nor is there any trace of a limiting-wall remaining. At times they appear as true, clearly defined circles, while at others the outline is less distinct, the clear crystalline calcite passing irregularly into the surrounding dark material. Spines of various sizes are common, projecting from the circles, though they are not present universally.

It is not without much hesitation that we suggest that these casts may represent radiolaria, for in default of the characteristic structure of the test it is not possible to give an absolute opinion. They are usually associated with a few sponge-spicules. In thin sections there is a very remarkable superficial resemblance between these rocks with their calcite-casts and the radiolarian Culm rocks described by Dr. G. J. Hinde & Mr. Howard Fox,[1] or those from the Devonian mentioned by Dr. Rüst.[2] Dr. Hinde has very kindly looked over some of our slides and admits the resemblance, though he could not find any remains of the structure of the test.

These calcite-casts, it will be observed, are always found in the calcareous rocks, and their condition is in entire agreement with the observations of Messrs. Hill & Jukes-Browne on the fossilization of radiolaria in the Chalk and the Barbados deposits. Thus on p. 604, Quart. Journ. Geol. Soc. vol. li (1895), they say:—

'.... it will be seen that, while in calcareous rocks where radiolarians are indubitably present, it frequently happens that nothing but their outline

---

[1] Quart. Journ. Geol. Soc. vol. li (1895) pp. 609–67.

[2] 'Beitr. zur Kenntniss d. foss. Radiolarien' Palæontographica, vol. xxxviii (1892) pp. 113–14 *et seqq.*

remains, our slides show all stages in the transformation of a siliceous radiolarian into a structureless ball or disc filled with calcareous matter or into a mere patch of clear crystalline material.'

The foregoing passage precisely describes the condition seen in our slides.

The limestone of Wooladon Quarry, near Launceston, described by Dr. Hinde & Mr. Fox in vol. li (1895) of this Journal, p. 633, as

'finely granular, with some traces of calcareous organisms and a few rounded bodies, now infilled with calcite, which may possibly be casts of radiolaria,'

seems to be similar to these Pendle rocks.

Unfortunately there is not sufficient development of chert in the hard black rocks to enable us to trace the form of the bodies more clearly; where chert does occur, it is usually in the softer black rock, and generally shows sponge-remains only. Whatever these organisms may eventually prove to be, they are singularly constant in their occurrence in the Pendleside Limestone of the black type, for we find them on Pendle Hill; Denning Dale, near Skipton; Flasby Fell; Poolvash (Isle of Man); Barber's Booth, in the Peak; Doveholes, near Castleton, and at Stanton Leys (Derbyshire); Morridge and the Dane Valley in Staffordshire; Pule Hill, Marsden (Lancashire); and at other places within our area. Though usually, they are not invariably, present in these limestones; thus at Tolls Wood, Stanton (Derbyshire), a dark rock with small lenticular patches of chert lying parallel to the bedding shows scarcely any whole organisms at all, and only a little fragmentary material lying very regularly in an opaque reddish to black groundmass, which is finely laminated and full of plant-fragments. The chert in this rock is dark-yellow in section and no organisms are seen in it, though certain rounded outlines may mark the position occupied by foraminifera.

At the fall in the stream under Pendleton Hall the radiolarian (?) casts are fairly abundant, together with faint indications of goniatites, in a peculiar rock, greenish-brown on weathered surfaces, but blue on fresh surfaces, blotched with purple and grey patches, very hard and compact, and exhibiting a tendency to conchoidal fracture. In section, it is seen to possess a finely granular crystalline structure, and is stained irregularly with iron-oxides.

Whether these bodies have been radiolaria or not is a question which we hope before long to settle definitely. Meanwhile they certainly invite comparison with the better defined, undoubted radiolaria of the Culm, more especially as they are associated with an almost identical fauna.

Appendices A & B (facing p. 402).

The accompanying tables, drawn up from personal collecting and from notes of well-authenticated specimens in public collections, demonstrate—firstly, the essential differences in the faunas of the Carboniferous Limestone and Yoredale Series from that of the Pendleside Group; secondly, the similarity of the fauna found in the massive Carboniferous Limestone of Clitheroe, Derbyshire, and

Craven with that of the Yoredale Series of Northern Yorkshire; and thirdly, the true position of the inliers of Ashnot, Bolland, Cracoe, and Thorpe in Craven. The lists do not in any way profess to be complete.

The corals, gasteropoda, and crustaceans have not been included, as the necessary details have not yet been obtained with sufficient accuracy for publication; but even now it is certain that the distribution of the corals, which are plentiful in the limestones of the Yoredale Series, will demonstrate the identity of the faunas in the Yoredale and Massive Limestones. The few gasteropods as yet obtained in the Pendleside fauna are, however, noted, and only a single coral (*Zaphrentis Enniskilleni*) has been recorded from this horizon.

In conclusion we wish to express our sincere thanks for the help most generously afforded to us by Dr. G. J. Hinde, F.R.S., Dr. Henry Woodward, F.R.S., Mr. George C. Crick, and Dr. A. H. Foord in the determination of specimens.

PLATE XIV.

Comparative vertical sections of the Pendleside Group, on the scale of 80 feet to the inch.

Discussion.

Mr. Marr bore testimony to the value of the work which Dr. Hind was carrying out with such enthusiasm. He was much impressed, when in the field with Dr. Hind, by the way in which that worker had predicted the occurrence of the Pendleside fauna in certain beds near Cracoe, and had then found them. But he (the speaker) would like more information concerning the faunas below this. Dr. Hind maintained that the great group of 'shales with limestones,' which had by other workers been intercalated between two sets of limestone, came above the Pendleside Limestone, and that the beds between the base of the Great Scar Limestone and the Upper Scar Limestone lying north of the Craven Fault were all represented by limestone to the south of that fault. He (the speaker) felt that this question could only be satisfactorily settled by working out in detail the faunas of the limestones and shales to the north of the Craven Fault; this he believed had never yet been satisfactorily accomplished, and if the Authors had not done it in the paper of which they had necessarily given only a brief abstract, he hoped that it would be done ere long.

Prof. Garwood congratulated the Authors on the results of their careful work in the Pendleside Limestone Group. He could not, however, quite follow the evidence of the fluviomarine origin of the beds. With regard to Dr. Hind's classification of the whole of the Mountain Limestone and Yoredale Series as the zone of *Productus*

[illegible]	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	E.
Scaldia Benedeniana	...	...	...	...	...	...	...	...	...	...	*	...	...	...	...	...	...	...	...	...	...	E.
Solenomya primæva	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	E.
CEPHALOPODA.																						
Actinoceras Breynii	*	*	*	...	...	...	...	...	...	...	*											
A. giganteum	...	*	*	...	...	...	...	...	...	...	*											
Cœlonautilus subsulcatus	...	...	*	...	...	...	...	?	...	...	*											
Discites discus	...	...	...	...	...	...	...	*	...	...	*											
D. planotergatus	...	*	*	*	...	...	...	...	...	...	*											
D. sulcatus	...	...	...	*	...	...	...	...	...	...	*											
Glyphioceras crenistria	...	...	*	*	...	...	...	*	...	...	*											
Gl. mutabile	*	*	*	*	...	...	...	*	...	...	*											
Gl. sphæricum	*	...	*	*	*	...	...	*	...	...	*											
Gl. striatum	...	...	*	*	...	...	...	*	...	...	*											
Gl. truncatum	...	*	*	*	*	...	...	*	...	...	*											
Nomismoceras rotiforme	...	*	...	...	...	...	...	*														
N. vittigerum	...	*	*	*	...	...	...	*	...	...	*											
Phacoceras oxystomus	...	...	...	*	...	...	...	...	...	...	*											
Prolecanites compressus	...	...	...	...	...	...	...	...	...	*												
Pronorites cyclolobus	...	*	...	...	...	...	...	*														
Solenocheilus cyclostoma	...	...	...	...	...	...	...	*														
S. dorsalis	...	...	*	...	*	...	...	...	...	...	*											
Stroboceras bisulcatum	...	...	*	...	...	...	...	*	...	...	*											
Temnocheilus coronatus	...	...	...	*	...	...	...	*	?													
Thrincoceras Hyatti	*	...	...	...	...	...	...	...	...	...	*											

E. = Eden Valley, Swarth, Wild Boar, Nine Standards Fells, Mallerstang. G. = Garsdale. R. = Ravenstonedale.
S. = Swaledale. W. = Wensleydale.

urn

	Und	Pen	Par L	Fla	Bur T	Blac	Rive D	New	Crin H ne	Mix	Mai	Dov G	Tiss	Dan	Mar	Pool P	Cong	Upp Sh	Ven Cu	Pass Lo
... Brown	...	*	...	*	...	...	*	*	*	*	...	...	...	...	...	...	...	...	...	*
O. Koninckianum	...	...	...	...	...	...	...	...	*											
O. Steinhaueri	...	*	...	*	...	...	?	...	*	*	...	...	...	...	*	?	*	*	...	*
O. sulcatum	...	...	...	...	...	*	...	...	*	...	...	...	...	...	*	*	...	...	*	
Prolecanites compressus	*	*																		
Pr. serpentinus	...	...	...	...	...	*	...	...	...	...	...	...	...	...	...	*				
Temnocheilus carbonarius	...	...	...	...	...	...	...	...	*	...	...	..	...	...	...	...	...	...	...	*
T. concavus	...	...	...	...	...	...	...	...	*	...	...	...	...	...	...	...	...	...	...	*
GASTEROPODA.																				
Bellerophon Urei	*	*	...	*	...	*	...	...	*	...	...	...	...	...	*	...	*	*		
Macrocheilina elegans	...	...	...	...	...	...	...	...	*	...	...	...	...	...	*	...	...	...	...	*
M. Gibsoni	...	...	...	...	...	...	...	...	*	...	...	...	...	...	*	...	...	...	...	*
M. reticulata	...	...	...	...	...	...	...	...	*	...	...	...	...	...	*					
PISCES.																				
Acrolepis Hopkinsi	...	...	...	...	...	...	...	...	...	...	...	...	...	*	*	...	...	...	...	*
Cladodus sp.	...	...	...	...	*	...	...	...	*											
Elonichthys Aitkeni	...	...	...	...	...	...	...	...	*	...	...	...	...	...	*	...	...	...	...	*
Orodus sp.	...	...	...	...	...	...	...	...	*											

[1] It is to be regretted that the name *Aviculopecten* will have to be changed for this shell. Revision of the *Pecten*-like shells of the Carboniferous rocks shows that several distinct genera have been included under *Aviculopecten*, the type of which, *A. planoradiatus*, differs much from *A. papyraceus*, which should probably be referred to *Pterinopecten* of Hall.

and
con-
the
ımed
uth;
vely
ıugh

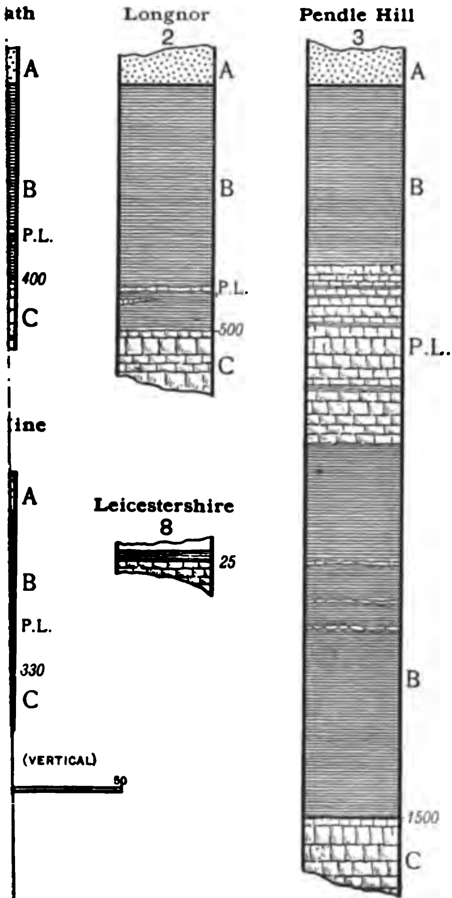
hich
had
ıire,
. on,
ndle
e, to
nti-
e.
ssil
the
dle-
ive,
nds
her
ssil.
heir
rata
ion,
ına,
r it
able

hat
top
vere
by
ntly

ood
that
cted
hon-
dis-
ntly,
vell-
ıous
ıters
ıge;
ısits

ROW

COMPARATIVE SECTIONS of th



giganteus, he would like to know whether *Chonetes papilionacea* and *Chætetes septosus* had been found throughout that zone, or were confined to the base; he would also like definite information as to the range of *Productus latissimus* in Dr. Hind's area. Dr. Hind mentioned that the Nuculidæ were found to rise in the beds from north to south; the speaker had found *Productus latissimus* to occur in successively higher limestones, as the beds were traced from Ingleborough through Weardale to Alnmouth.

Mr. Walcot Gibson remarked on the enthusiasm with which Dr. Hind conducted his researches and the interest which he had added to the study of the Carboniferous rocks. In North Staffordshire, as the re-survey of the Lower Carboniferous rocks was carried on, the Pendleside Group was found in the same position as on Pendle Hill; while the fossiliferous bands and nodules of dark limestone, to which Dr. Hind had drawn attention, were of much value in identifying the grits and shales overlying the Carboniferous Limestone.

Mr. Strahan pointed out an inconsistency in the use of the fossil evidence. Whereas the occurrence of *Productus giganteus* in the Yoredale Beds of Wensleydale and in the main limestone of Pendleside was taken to prove that these deposits were strictly correlative, the occurrence of Nuculidæ in the Coal-Measures of the Midlands and in the Calciferous Sandstone of Fife was explained on another theory. *Productus giganteus* was not to be trusted as a zone-fossil. Moreover it occurred only in the thin limestones, and in their absence the evidence for the correlation of the Wensleydale strata disappeared. He did not, however, disagree with that correlation, and considered that a higher subdivision, with a distinct fauna, existed in North Wales and the Isle of Man, though how far it coincided with the Authors' 'Pendleside Beds' he was unable to say.

With respect to the supposed radiolaria, he might say that during the past year radiolaria had been found in cherts at the top of the Carboniferous Limestone Series in South Wales. Some were represented by translucent discs not unlike those exhibited by Mr. Howe, while in others radiolarian structure was sufficiently preserved for purposes of identification.

Mr. Lamplugh, in congratulating the Authors upon the good results already attained, asked whether they could be certain that the species selected as typical of the Pendleside Series were unaffected by the 'isodietic' distribution which had been so strikingly demonstrated in regard to some other species. It was somewhat disquieting to learn that fossils could shift their horizon so persistently, and within so restricted an area, that their life-limits formed well-defined 'zones' passing obliquely across the lines of synchronous deposition. It was already agreed that the lithological characters of the sediments of this age underwent great horizontal change; and under such conditions the correlation of the synchronous deposits of the series in separate areas must be extremely difficult.

Mr. H. B. Woodward, the Rev. J. F. Blake, and Mr. G. Barrow also spoke.

Dr. Wheelton Hind, in reply, said that isodietic lines show similar conditions. Zonal lines show time, and the former may cut the latter obliquely. The fauna of the Yoredale Shales of Wensleydale yields as yet no goniatites or other forms of the Pendleside type.

In the recurring limestones of Wensleydale *Productus giganteus* recurs, but in the Pendleside Series neither *Pr. giganteus*, *Pr. latissimus*, nor *Chonetes papilionacea* have ever yet been found. The Pendleside Group is the name proposed for the 'shales-with-limestones' of the Geological Survey.

28. *The* INFLUENCE *of the* WINDS *upon* CLIMATE *during the* PLEISTOCENE EPOCH: *a* PALÆOMETEOROLOGICAL EXPLANATION *of* SOME GEOLOGICAL PROBLEMS.[1] By FREDERIC WILLIAM HARMER, Esq., F.G.S. (Read May 8th, 1901.)

CONTENTS.

I. INTRODUCTORY.

THE progress of meteorological science during recent years has given us much information as to the causes of the constant, and to a superficial observer the apparently capricious, changes of weather which obtain over certain portions of the earth's surface. We understand now, not only why, in Great Britain for example, one day is dry or cold, and the next rainy or warm; but also why the general character of the seasons often differs so widely from the normal, the climate of spring being experienced at one time in January, and the conditions of winter in May or June. The scientific meteorologist, equally with the unlettered peasant, still looks, however, to the vane on the church-tower for his first explanation of anomalous weather, though the meteorologist shows us that the direction of the winds is due to the relative position, and to the form and alignment, of areas of high and low barometric pressure. The winds must necessarily blow, as is well known, in a direction more or less parallel to the isobaric lines, moving in the Northern Hemisphere outward from, and round the centre of, an anticyclone in the direction of the hands of a watch, and towards and round a cyclone in the opposite direction. To use the old formula (Buys Ballot's law), 'if you stand with your back to the wind, you have the higher barometer on your right hand.'

[1] The views expressed in this paper were laid before the Bradford Meeting of the British Association in September, 1900; see Geol. Mag. 1900, p. 565.

The comparatively genial climate of Great Britain during the winter is attributed to the Gulf Stream (using the term in its popular sense), but the action of the latter is indirect rather than direct; when the wind blows from the north-east, the influence which it exerts on our thermometers is practically *nil*. No one asks, when the weather suddenly becomes colder, whether the Gulf Stream is running in diminished volume, but whether the wind has not changed. If winds from the north, or the east, were as prevalent during winter as they are in spring, the yearly average temperature of these islands would be much lower than it is at present.[1] It is somewhat strange that, in their speculations as to the causes of the anomalous climates of the past, and especially of those of the Pleistocene Epoch, although geologists have fully recognized the important part played by marine currents, as well as the influence of winds upon the latter, they have seldom enquired how far climatic disturbances may have been due to the variations of the winds themselves.[2] Aerial currents may, however, in the course of a few hours, wholly change the temporary climate of any district, by bringing over it vast volumes of air from regions to the north, or the south, as the case may be.[3] Seasons, abnormally warm or cold, rainy or dry, may be caused in like manner, though the course of the oceanic circulation remain the same; and permanent alterations would equally result, were the direction of the prevalent winds permanently changed.

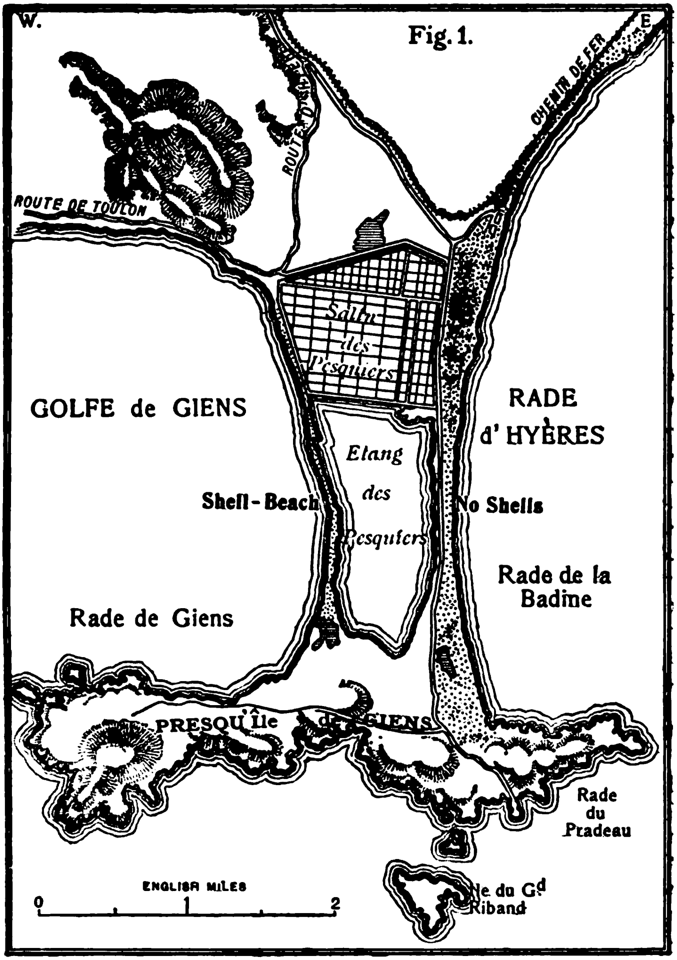
It may be profitable, therefore, to enquire whether any of the cases of anomalous climate which obtained during the latest part of the Tertiary Epoch may have been brought about in this way. It will not be difficult to show that the meteorological conditions of that epoch must have differed from those of our own times.

If, by bringing the teachings of geology and meteorology together, we can ascertain the prevalent direction of the winds in different parts of the Northern Hemisphere during past ages, we may reach, I believe, conclusions interesting to students of both sciences, which may at the same time suggest a reasonable solution of some geological difficulties. Abnormal conditions of climate in former

[1] It is true that marine and aerial currents are closely connected, and that they act and react on each other, often cumulatively; the action of the latter is, however, the more rapid and far-reaching of the two.

[2] In a paper published in 1869 (Trans. Roy. Soc. Edin. vol. xxv, p. 592) Dr. Buchan, while pointing out that temperature and rainfall are influenced by the direction of the prevailing winds, suggested that alterations in the distribution of land and water during past epochs would have reacted upon climate. The view here taken, however, is that climatal changes may also have been produced by variations in the relative position of areas of high and low barometric pressure, even when, as in Pleistocene and prehistoric times, the relation of the continental and oceanic areas to each other was more or less similar to that of the present day.

[3] Mr. H. S. Eaton stated, in a Presidential address to the Meteorological Society (Quart. Journ. Met. Soc. vol. iii, 1877, p. 316), that during the Siege of Paris, a balloon travelled from that city to Norway, 1,000 miles in a direct line, in 15 hours.



times could only have occurred when the meteorological conditions were favourable.

My attention was called to this subject accidentally, while endeavouring to work out a geological problem, namely, that of the conditions under which the Upper Crag deposits of the East of England were accumulated. During a visit to Hyères, in the South-east of France, in the spring of 1899, I noticed that of the two low sandy beaches fringing the narrow spit which connects the peninsula of Giens with the mainland (see map, fig. 1), the beach to the west,

several miles in length, facing the Gulf of Giens, was covered, from end to end, with the shells of dead molluscs, while upon that facing the east, towards the roadstead of Hyères, not a single shell was to be found. The reason for this was obvious: the north-westerly mistral was then blowing upon the western beach, causing considerable surf, while upon the other, where no shells occurred, protected as it was by the isthmus, the sea was perfectly calm. This incident seemed to throw light on a difficulty which had perplexed me for many years.

The Crag deposits referred to, originating as beaches against the shore, or as shoals in shallow water, as I have endeavoured to show in a former paper,[1] were the littoral accumulations, during later Pliocene times, of the English margin of the North Sea, which then extended somewhat farther westward than it does at present. They are composed of loose sand, and, as is well known, contain everywhere, and in inconceivable profusion, over a more or less continuous area of 60 miles from south to north, the drifted and often fragmentary shells of dead mollusca.

At present, dead shells are but seldom met with on the eastern shores of the counties of Norfolk and Suffolk, although on rare occasions they are cast up there in greater or less abundance. One may usually walk for miles along the beach at Yarmouth or Lowestoft without finding more than a chance specimen. That this is not due to any absence of molluscan life from the adjoining sea, my son, Dr. Sidney F. Harmer, F.R.S., and I have ascertained by dredging. The conditions under which the Crag beds were deposited must therefore have been different from those now obtaining in the same area, and the idea suggested itself to me that easterly gales might have been prevalent then in that part of the North Sea, rather than those from a westerly quarter, as at present.

Investigating the matter further, I ascertained, during a visit in 1899 to the coast of Holland with my friend, Dr. J. Lorié, of Utrecht, that the beaches of that country are as plentifully strewn with the shells of dead molluscs as were those of East Anglia during the Crag Period. Enormous quantities of shells are constantly collected on the Dutch shores for lime-burning, and I was informed by Dr. Hoek, the Superintendent of the Zoological Station at the Helder, that the shell-gatherers find their best harvest after storms attended by westerly winds.[2]

The accumulation of shell-beaches in Western Europe is local rather than general, but they are common on those coasts of France and of the British Isles, facing the west, which are exposed to storms from the Atlantic, and rare in the East of England, though they occur on the north-eastern coast of Scotland, as at St. Andrews, where easterly gales are more frequent in winter than they are farther south. Prof. M'Intosh, writing from that town, informs

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 728.

[2] I noticed also two powerful steam-dredgers at work in a disused channel of the River Maas, near the Hoek van Holland, now nearly silted up, which raise, I was informed, 100,000 tons of dead shells annually.

me that it is after, rather than during, easterly gales, that shells are especially cast up by the sea.

The sea is agitated during storms to a greater or less depth, according to their violence, and the size of the waves caused by them. Mollusca are at such times rooted up from their usual habitat, and moved forward along the bottom in the direction towards which the wind is blowing. They do not reach the shore during the storm, but after it has ceased. The effect of a strong wind blowing on-shore is to heap up the water against it, and to cause the removal of beach by the undertow of the retreating waves, rather than its accumulation. The material so removed is not carried out far, however, but returns when the wind drops, bringing the dead shells that have become mixed with it during the gale. I learned a short time ago from Mr. A. Patterson, of Yarmouth, that on December 12th or 13th, 1899, the beach at that place, where usually no shells occur, was in places covered with them. On referring to the Daily Weather Charts of the English Meteorological Office, I found that the direction and the velocity of the wind, for several days before, had there been as follows:—

	Dec. 7th.	8th.	9th.	10th.	11th.	12th.
Direction.........	E.S.E.	E.S.E.	E.S.E.	W.S.W.	E.	W.
Force	8	8	6	2	5	2

When the storm abated, the shells were thrown upon the beach. A day or two afterwards, they had quite disappeared, having been covered with sand.

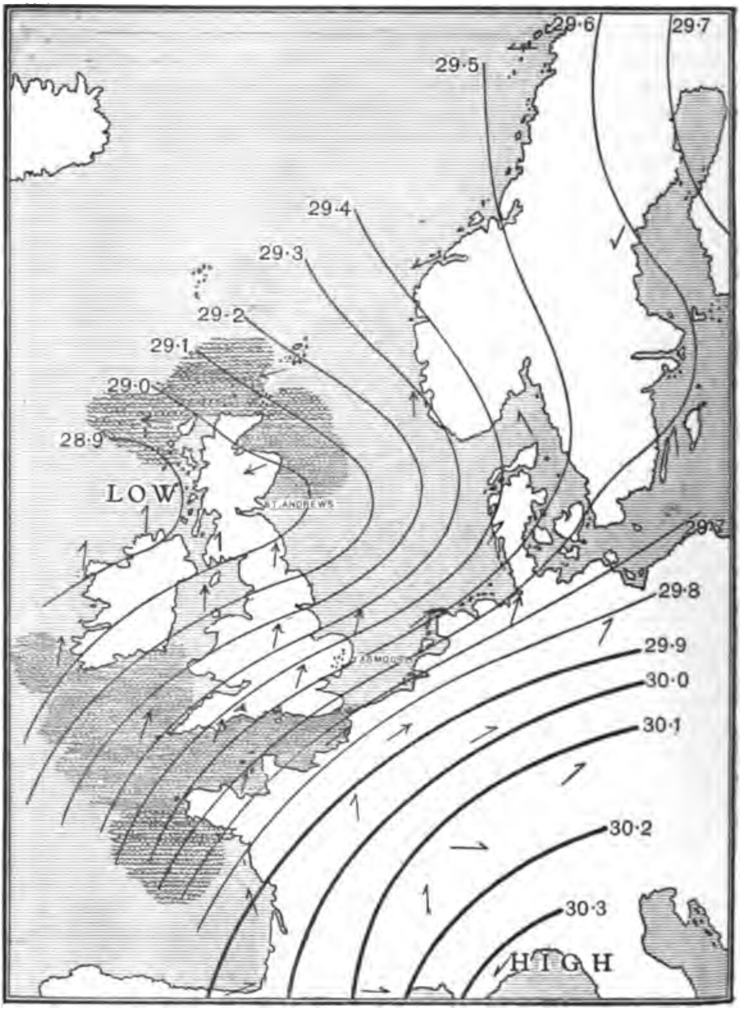
Meteorology may explain, I think, why dead shells were so constantly cast up on the shores of East Anglia during the Crag Period. The centres of the cyclonic disturbances which approach the British Isles from the Atlantic, pass for the most part, especially during the winter months, to the north or north-west of that portion of the German Ocean which intervenes between Suffolk and Holland. Hence westerly gales (from south-west to north-west) there prevail, and rough seas are common, not only on the Dutch coasts, but on those of France and Great Britain that face the west, and on the eastern coast of Scotland. A typical example of this is given in fig. 2, p. 410, reproduced from the daily weather-chart for January 21st, 1899.

When the regions to the north of Great Britain are anticyclonic, however, which is not often the case during the winter, though this occurred, for instance, on October 17th, 1898 (fig. 3, p. 411), cyclonic storms take a more southerly course, causing easterly and south-easterly gales and rough weather in the East of England.[1] Similar conditions may have prevailed, I think, in later Pliocene times.

As has been long known, the molluscan fauna of the North Sea was characteristically southern during the earlier stages of the

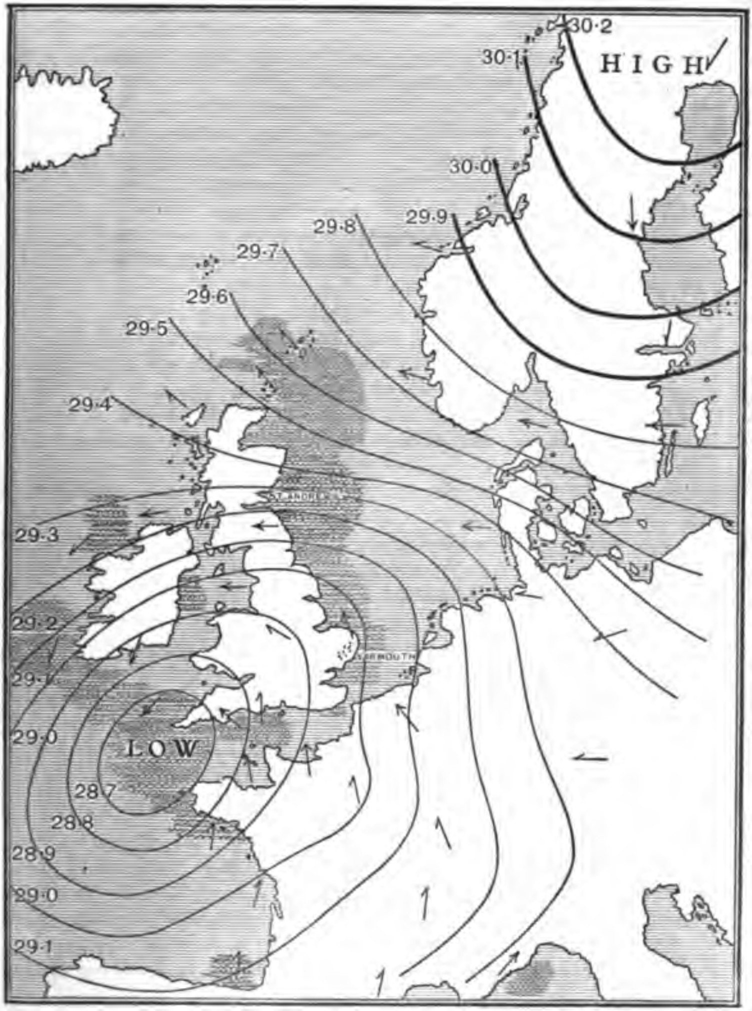
[1] The weather-charts for the days mentioned above are of a character similar to those reproduced in figs. 2 & 3.

Fig. 2.— *Weather-chart for Saturday, January 21st, 1899.*



[The dots in the East Anglian area indicate the position of the Crag-beds.]

Fig. 3.—*Weather-chart for Monday, October 17th, 1898.*



[The dots in the East Anglian area indicate the position of the Crag-beds.]

Pliocene Epoch, resembling that of the Mediterranean or even the Azores, but as the Great Ice Age approached and the climate became colder, the Crag area was invaded by boreal and arctic mollusca, and such forms, at first gradually, and at length entirely, supplanted the southern shells. Early in the Red Crag period, species such as *Natica clausa*, and later on, those like *Cardium grœnlandicum*, *Tellina calcarea*, and *Astarte borealis*, now found only to the north of the Arctic Circle, had established themselves in the German Ocean as far south as lat. 52° N. We may therefore conclude, I think, that the climate of regions to the north of Great Britain had, in all probability, by that time become considerably colder than now, and therefore frequently anticyclonic in winter, an ice-sheet having permanently established itself on the Scandinavian highlands. This being the case, cyclones would have then been diverted to the south of the course which now they usually take at that season, and easterly rather than westerly gales would have been prevalent in the Crag area.[1]

This matter, comparatively unimportant in itself, seemed to open the way to enquiries of wider scope and of considerable interest.[2]

It is not only dead shells, for example, that are now blown towards the shores of Holland by westerly gales. Extensive sandbanks exist off the Dutch coast, whence material is transferred to the beach, and thence is blown inland to form immense dunes, some of them, as in the island of Texel, being more than 2 miles wide. In Norfolk, on the contrary, the few sand-dunes that exist are very narrow, and their preservation is a constant source of anxiety to the local authorities. The 10-fathom line hugs the English coast very closely, but it extends a considerable distance, sometimes 10 miles, from that of Holland.

Similar conditions exist in the Irish Sea, which is shallower near its eastern than its western margin.[3] Although partly due to other causes, the piling-up of sediment in the Irish and the North Seas on the one side rather than on the other must be chiefly attributed, I think, to the action of the winds now prevalent, and, if so, it may be worthy of consideration how far the varying thickness of some of the deposits of former periods may have been caused in a similar way.

The establishment of a permanent ice-sheet, the meteorological conditions of which may have been more or less prevalently anticyclonic, first over Scandinavia, and at a later period over the British Isles and a great part of Northern Europe, together with the former existence of similar ice-fields (on an even more extensive scale) in North America, assuming that such an explanation of the

[1] A preliminary note on this subject, published in short abstract only, was presented to the Meeting of the British Association at Dover in 1899; see Brit. Assoc. Report, p. 753.

[2] See also M. Paul Tutkowski's views on the origin of lœss, Scot. Geogr. Mag. vol. xvi (1900) p. 171.

[3] See Map in 10th Annual Report of the Liverpool Marine Biology Committee (1897) p. 17.

Glacial phenomena may be accepted, must have profoundly affected the distribution of barometric pressure in the Northern Hemisphere, and have set up changes of a far-reaching character. Before attempting, however, to restore hypothetically the meteorological conditions of the Pleistocene Epoch, it seems desirable, as briefly as possible, to call attention to the salient features of those of our own day.

Through the courtesy of Mr. W. N. Shaw, F.R.S., of the British Meteorological Office, I have been permitted to consult the 'Tägliche synoptische Wetterkarten' of the North Atlantic and the adjacent continents, issued under the joint supervision of the Danish and Hamburg Meteorological Offices, and the Bulletins of International Meteorology of the War Department of the United States, in the library of the first-named institution; and I have also taken advantage of the maps in the reports of the *Challenger* Expedition,[1] and in the recently published 'Atlas of Meteorology.'

These maps show that in certain portions of the earth's surface the meteorological conditions are more or less permanent. This is especially the case in the Southern Hemisphere, as will be seen in figs. 4 & 5 (pp. 414 & 415), and figs. 6 & 7 (pp. 418 & 419), reproduced from the 'Atlas of Meteorology,' by the kind permission of Dr. A. Buchan, F.R.S., and Mr. J. G. Bartholomew, F.R.S.E.[2]

South of lat. 40° S. there exists, at all times of the year, a trough of low barometric pressure, with a complementary belt of high pressure to the north of it. The latter is not continuous during the summer months, but tends then to break up and leave the land; it not only covers a much larger area during the southern winter, but extends at that season farther northward, encroaching upon and pressing northward the low-pressure belt of the Equatorial region. The relative position of these belts of high and low pressure in the Southern Hemisphere, and the east-and-west alignment of the isobaric lines to the south of lat. 40° S. throughout the whole year, is accompanied by a continuous prevalence there of westerly winds.

The state of things in the Northern Hemisphere, although conforming to the same general principle, differs in details, and the meteorological conditions are less permanent. Belts of high and low pressure, corresponding to those of the Southern Hemisphere, may be traced, but owing to the great amount of land north of the Equator, they are not continuous, and their relative position and alignment varies at different seasons.[3] The continents are hotter

[1] Report on Atmospheric Circulation, vol. ii, maps 1–52.

[2] Charts, whether isobaric, isothermal, or isohyetal, that are based on the annual averages, are, in enquiries of this kind, more or less misleading, as in many regions the atmospheric conditions differ at different seasons. An isobaric chart for the whole year, for example, shows the greater part of Asia as anticyclonic, but for three or four months during the summer the barometric pressure is there abnormally low (see fig. 5, p. 415). In considering the meteorology of the Pleistocene Epoch, it will be necessary, therefore, to deal separately with summer and winter.

[3] The normal planetary circulation of the atmosphere is modified in the Northern Hemisphere by the existing distribution of land and sea; and it must have been so too, I think, during the Pleistocene Epoch, even if it was, at that time, of a more intense character.

Fig. 4.—*Isobaric chart for January (statistical).* *From the 'Atlas of Meteorology,' pl. xii.*

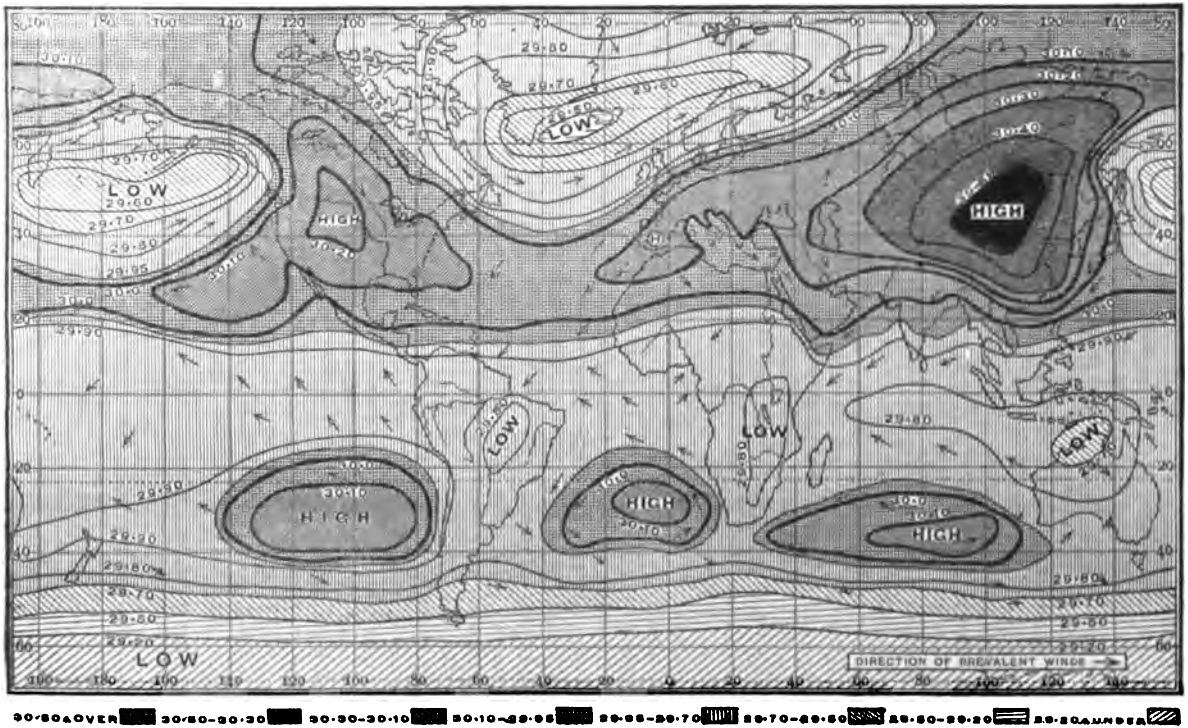
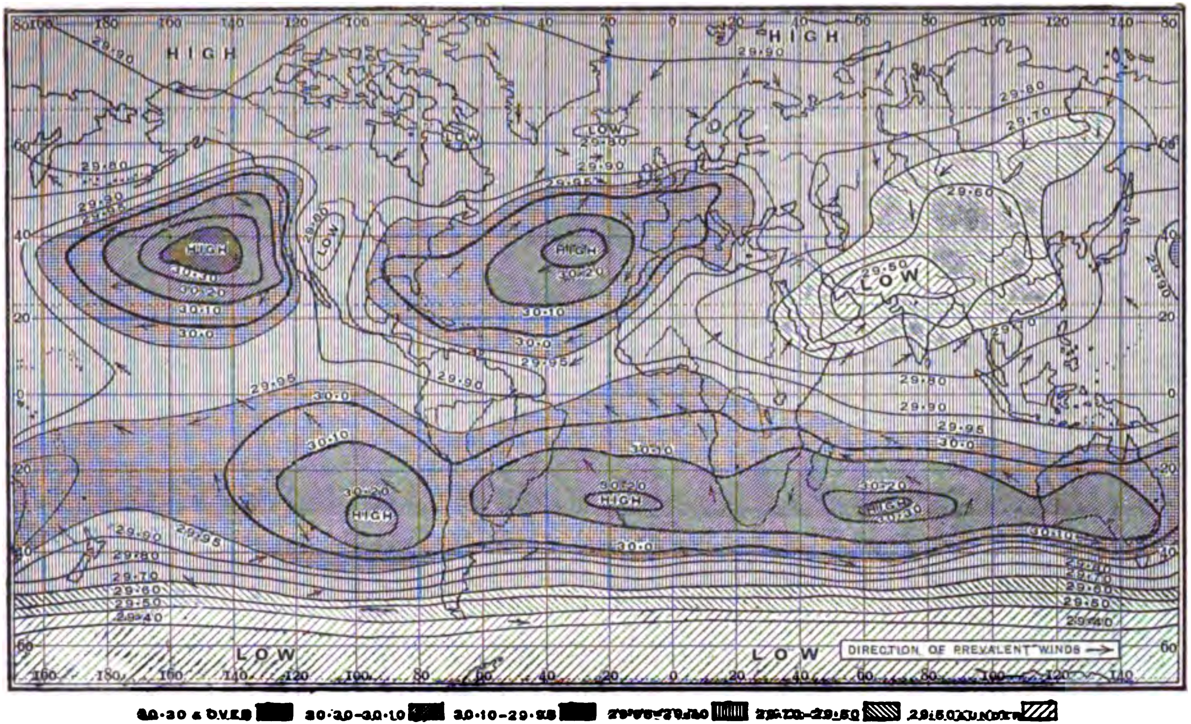


Fig. 5.—*Isobaric chart for July (statistical).* *From the 'Atlas of Meteorology,' pl. xii.*



than the ocean during the summer, and therefore cyclonic; they are colder in the winter and are then anticyclonic, and, as in the Southern Hemisphere, the anticyclones tend to leave the land for the ocean as spring advances, and to return to it in autumn. The high-pressure systems move also northward and southward with the sun. Certain meteorological features are, however, more or less permanent in the Northern Hemisphere. Anticyclones, forming a portion of the northern belt of high pressure, exist near the Tropic of Cancer, in the North Atlantic and in the North Pacific, at all seasons (figs. 4 & 5, pp. 414 & 415), though their form and position vary, not only from day to day, but seasonally also, and in winter they are statistically confluent with the anticyclones of the adjacent land-tracts. Well-marked areas of low pressure in the Northern Hemisphere are, moreover, predominant over the oceans for a great part of the year; one, shown in fig. 4, lies statistically in January over the North Pacific, immediately to the south of Behring Strait. This tends to become smaller as summer approaches, and nearly disappears during July (fig. 5), in the chart for which it appears as a small protruding lobe of the great Asiatic cyclone.

Low-pressure conditions largely prevail also in winter over the North Atlantic, though the actual position and form of this, as of other cyclonic systems, are constantly changing; and in summer it nearly disappears, being encroached upon by the Atlantic anticyclone.

The glaciated region of Greenland is always more or less an area of higher pressure than that occupied by the low-pressure system, called, for convenience, the Icelandic cyclone, and the former country is seldom traversed by the cyclonic disturbances which cross the Atlantic. They usually avoid it, passing well to the south.

In the Northern as in the Southern Hemisphere the general direction of the winds remains the same where the relative positions of high and low-pressure areas are unchanged, as in the case of the north-easterly trades, which conform at all times of the year to the more or less permanent relation between the anticyclone of the Azores and the Equatorial belt of low pressure. Even in that part of the Atlantic which lies north of lat. 40° N., and in the continents adjoining (regions—during a great part of the year—of constant atmospheric disturbance), although the isobaric lines are changing in direction and position from day to day, certain main features predominate at different seasons. Dr. Buchan's monthly charts are statistical only, and do not represent the actual conditions at any one time, being based on the averages for a number of years. Still they indicate generally the seasonal changes in the atmospheric conditions, and in the prevalent direction of the winds, upon which the varying climate of the temperate regions of the Northern Hemisphere so largely depends. It will be seen from these charts that it is to the position and form of the Icelandic depression, and the predominance of southerly and westerly winds over the British Isles and the Norwegian coast, even

more perhaps than to oceanic currents, that the comparatively mild winter climate of those countries is due, while a contrary influence is exerted by the cold winds which prevail over the regions of Labrador and a part of North America, situated on the west side of the cyclonic disturbances of the North Atlantic and to the east of the American anticyclone.

The influence of areas of high and low pressure upon climate depends, not merely on their relative position, but on their form and alignment. The air set in motion by a cyclone, circular in form, and of small diameter, does not travel far; on the contrary, a larger cyclone or one elliptical in shape, and so situated that its longest axis stretches a considerable distance from south to north, causes, on the one side of its centre, the rapid transference of volumes of heated air from regions far to the south, and, on the other side, of chilled air from the frozen north (see, for example, fig. 11, p. 437). Isobaric charts accordingly show that changes of weather such as those characteristic of the British climate are not only due to the daily or seasonal shifting or oscillation of the areas of low and of high pressure, but also to the continual changes in their form. In regions of disturbance like that of the North Atlantic, cyclones and anticyclones are, during portions of the year, in constant movement, pressing upon and eating into each other, and changing in form like the waves of a choppy sea. A comparatively slight disturbance may thus alter their shape, position, or alignment, and the direction of the winds at any spot.[1] Any important atmospheric disturbance at one point, however brought about, may consequently make its influence felt at a considerable distance from the focus of its origin.

Keeping these well-known facts in mind, we may now enquire how far the different meteorological conditions which may have been set up during the existence of ice-sheets in North America and in Eurasia, can be shown to be in harmony with, or explanatory of, the teachings of geology. These conditions were probably of a more permanent character than those now obtaining, since there would not have been then so great a difference as that which now exists between the winter and summer temperatures and barometric pressures of the continental regions. Anticyclonic centres may have existed at all seasons over the ice-clad areas,[2] while over the land to the south of them, and over the ocean, regions of comparative warmth, low-pressure conditions may generally have prevailed. The stronger contrast between the cyclonic and anticyclonic systems

[1] The interdependence of the movements of the high- and low-pressure systems was shown in an interesting paper by Major H. E. Rawson, Quart. Journ. Roy. Met. Soc. vol. xxiv (1898) p. 180.

[2] The meteorological observations made by the British Antarctic Expedition in lat. 71° S., showing a great preponderance of southerly over northerly winds, both in winter and summer, seem to favour the theory that the ice-sheet of the Antarctic regions is prevalently anticyclonic. See Borchgrevink's 'First on the Antarctic Continent' 1901, p. 304.

Fig. 6.—*Isothermal chart for January (statistical). From the 'Atlas of Meteorology,' pl. iii.*

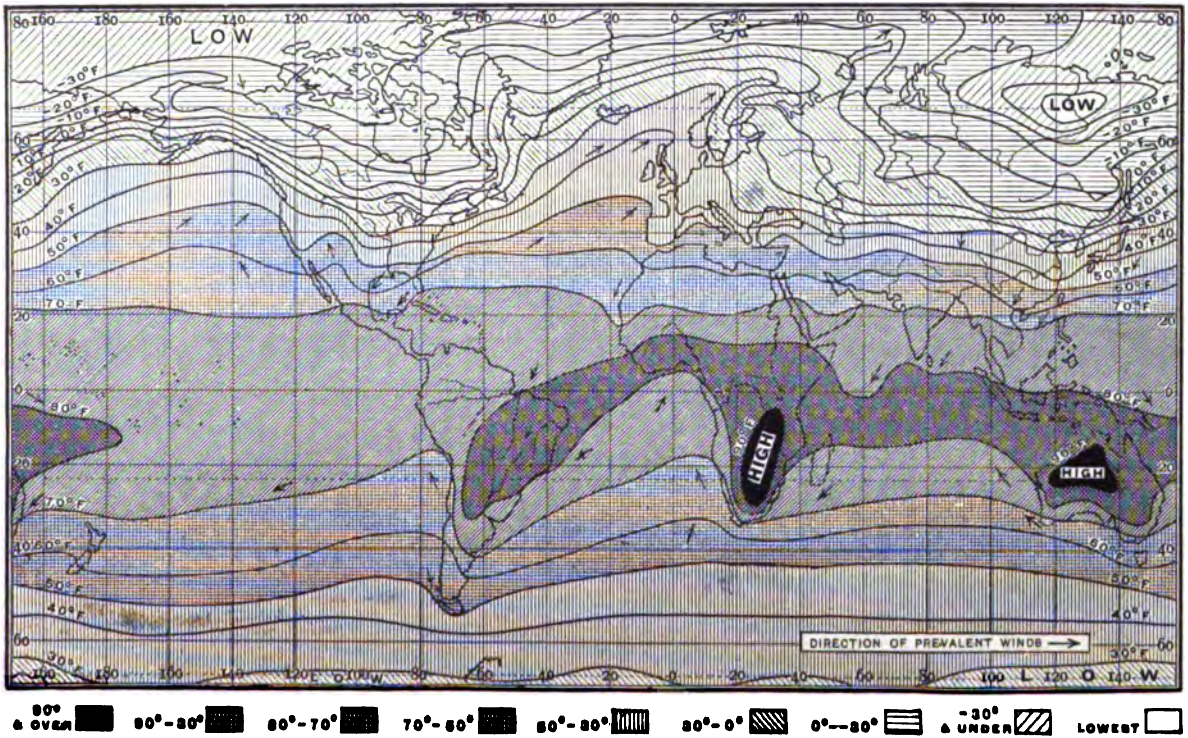
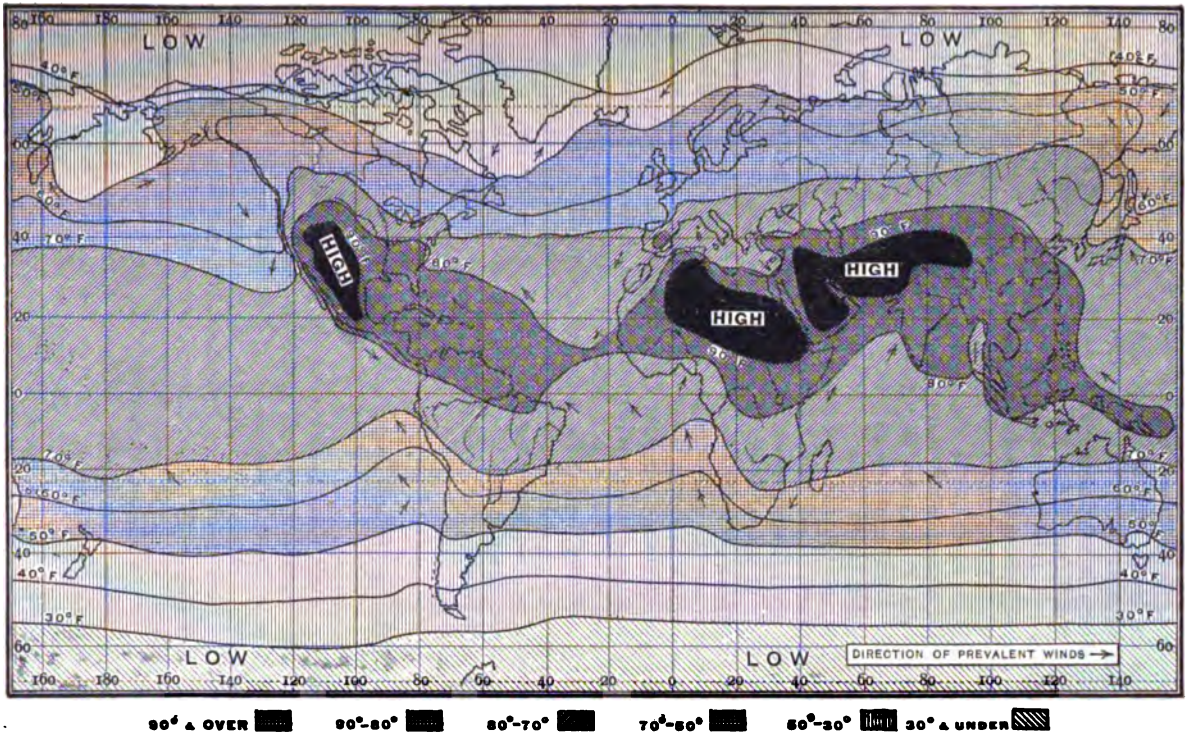


Fig. 7.—*Isothermal chart for July (statistical).* *From the 'Atlas of Meteorology,' pl. iii.*



and the climatic zones of the Northern Hemisphere must have caused increased atmospheric disturbance, so that storms would then have been more frequent and more violent; productive therefore, locally, of a more copious rainfall.

The present distribution of climatal zones in the Northern Hemisphere is very irregular, especially in winter, and a reference to figs. 6 & 7 (pp. 418 & 419), the statistical isothermal charts for January and July, will show that important deflexions of the isothermal lines from the normal coincide, as a rule, with the direction of the prevalent winds. Whatever may have been the case at more remote epochs, it is not probable that the alignment of the isotherms corresponded more nearly with the parallels of latitude during the Pleistocene Epoch than it does now. If at that time the Equatorial regions were hotter than those of the poles, there would have been a constant interchange between the heated air of the one and the cold air of the other. Moreover, the northerly winds and the southerly winds must always have directly or indirectly balanced each other. When the horizontal circulation of the atmosphere takes place round an area either of low or of high pressure (as for example in fig. 12, p. 439), the cold weather on the one side of the baric centre is the necessary complement of the warm weather on the other. The difference in the arrangement of the isobars during the Pleistocene Epoch, involving changes in the direction of the prevalent winds, would, however, have caused variations in climate of a more or less permanent character, widely differing from those of the present day. Oceanic winds with copious rainfall may have then prevailed in regions now arid, and mild winters where they are now excessively severe.

In illustration of this view it will be sufficient to point to one or two well-known cases of anomalous climate during the Pleistocene Epoch.

II. The Humid Conditions of the Sahara during the Pleistocene Epoch.

It has long been known that the Great Saharan Desert, now rainless, formerly enjoyed, probably during some part of the Pleistocene Epoch, a comparatively humid climate. No rain falls there now, because at all times of the year the winds blow towards it either from the land, or from the north, and not from the ocean. In other parts of Africa, and in some tropical or subtropical regions, on the contrary, as in India for example, rainy and dry seasons are alternate. In the latter country, the winds blow from the land during the winter months, as pressure is then highest towards the north. In summer, however, the barometric conditions are reversed, causing a strong indraught of south-easterly winds from the Arabian Sea, and where they prevail, the country is deluged with rain.

Similarly, the humid conditions formerly existing in the North of Africa could only have arisen from the prevalence of westerly or

south-westerly winds,[1] associated with the presence of lower pressure to the north. The Pleistocene savage of that region, sheltering himself behind a rock or a sandhill from the tropical rain, with his back to the west, must always have had, to use the formula quoted on p. 405, the higher barometric pressure on his right, and the lower on his left hand.

It is not difficult to understand how this state of things might have arisen. At present, when a high-pressure system lies over the North of Europe, the barometer is often low in the Mediterranean area, cyclones and anticyclones being necessarily complementary, one to the other, as are the troughs and crests of the waves of the sea. During the Pleistocene Epoch also, high-pressure conditions, more or less permanent, over the European ice-sheet, would have been attended by lower pressure over the warmer regions to the south of it, but the cyclonic centres would have sometimes reached farther south than at present. Moreover, I think, for reasons assigned later on, that during the period of maximum glaciation in Europe,[2] the Gulf Stream must have been excluded from the Arctic Ocean, possibly by the elevation of the submarine ridge which exists between Greenland and Scandinavia, or by its being blocked with ice, causing the Polar Sea to the north of it to be more or less permanently frozen over, at any rate in winter. If this were so, high-pressure conditions might have been then more or less prevalent from Davis Strait to the Ural Mountains. The influence of an anticyclone of such importance in the north must have tended to drive southward the low-pressure area of the North Atlantic, and with it the anticyclone now lying at all seasons of the year off the western coast of Morocco, the position of which prevents winds from the ocean from blowing over the Sahara (figs. 4 & 5, pp. 414 & 415). I have given hypothetically in fig. 21 (p. 458) the meteorological conditions under which moist winds from the ocean might have caused a humid climate in the Saharan region.

It is not necessary to suppose that during the Pleistocene Epoch the low-pressure system of the Mediterranean region always occupied the same actual position. It would not only have shifted from day to day as cyclones do at present, but seasonally also, now to the north, and again to the south, in accordance with changes in the situation of the anticyclone of the European ice-sheet, but the latter, I think, must have been prevalently an area of higher pressure than that of the warmer regions immediately south or west of it. At present the Greenlandic anticyclone sometimes extends far southward, and at other times it recedes, changing for the better or the worse the temporary climate of the Atlantic and of the British Isles. Similar changes must have occurred

[1] No moisture reaches the Sahara at present from the Mediterranean, as it is intercepted by the Atlas Mountains, and this must also have been the case during the Pleistocene Epoch.

[2] I shall state my reasons farther on (p. 435) for thinking that the maximum glaciation of North America may not have been coincident with that of Europe.

from time to time in the countries bordering on the Mediterranean during the Glacial Period.

Cyclonic storms from the Atlantic hardly touch the northern coast of Africa at present, but in Pleistocene times they might now and then have been diverted to the south of the Atlas Mountains by the existence of the anticyclone of the European ice-sheet, so bringing rain-bearing winds over the Sahara (fig. 21, p. 458).

A similar explanation may be given, I think, of the pluvial conditions (implying not only a greater rainfall, but also storms of considerable violence) which formerly existed in Syria and Palestine, and in parts of Arabia. These, contemporaneous, in Prof. Hull's opinion, with the glaciation of Hermon and Lebanon,[1] must have been due to an arrangement of the isobaric lines different from that now existing in the Levant. Winds blowing from the Mediterranean or from the Red Sea might have been, in that case, prevalent in Syria, their moisture being condensed by the colder air of the hill-countries of these regions.[2]

III. The Former Existence of the Mammoth on the Shores of the Polar Sea.

Meteorology may perhaps explain the former abundance of mammalian life in the extreme north of Asia.

The mammoth (*Elephas primigenius*) is known to have had a wide distribution in Pleistocene times, but nowhere are its remains more common than along the Asiatic shores of the Polar Sea. They occur in all parts of Northern Siberia, from the Ural Mountains to Behring Strait, and east of the latter in Alaska[3]; as well as in the Aleutian, the Pribilof, and the Liakof Archipelagos, the latter being situated as far north as lat. 75° N. Russian geologists believe that the mammoth and its contemporaries, among which the moose, a woodland form, may be specially mentioned,[4] lived where their fossil skeletons are found. Although *Elephas primigenius* was more or less a boreal species, it could not have flourished except in a district in which its natural food was abundant; but the extreme northern limit of the forests lies now considerably to the south of the region in question.

At present the summer temperature of Northern Siberia is not especially cold, but is as warm as that of Norway, the July isotherm of 50° Fahr. intersecting alike the North Cape and the coast-line of the province of Yakutsk (fig. 7, p. 419). On the contrary, its winter climate is exceedingly severe, the average temperature of one district in the extreme north of Siberia for January falling to

[1] 'Memoir on the Geology & Geography of Arabia Petræa, Palestine, &c.' 1889, p. 114.

[2] The question of the flood-gravels of Northern Italy and of Southern France is discussed later on (p. 463).

[3] An admirable summary of the facts connected with the range of the mammoth during the Pleistocene Epoch is given in Sir Henry Howorth's 'The Mammoth & the Flood' 1887.

[4] Quart. Journ. Geol. Soc. vol. l (1894) p. 7.

—51° Fahr.[1] It is, therefore, the winter conditions only of this region which now prevent the northward extension of the forest-zone.[2]

The January isotherms of the Northern Hemisphere (fig. 6, p. 418) are very irregular, that of 0° Fahr. reaching in Mongolia as far south as lat. 45° N. (the latitude of Turin), and towards the north, extending nearly to Spitsbergen.

As before urged (p. 420), it seems improbable that during the Pleistocene Epoch the winter isotherms were more nearly in accordance with the parallels of latitude than they are now, the climate of the Northern Hemisphere being then milder and more uniform. It is still less probable that the distribution of atmospheric pressure was similar to that of the present day, but with a generally increased temperature.[3] The more reasonable hypothesis seems to be that comparative heat and cold were at that time local, as they are at present, but that the winter climate of Northern Siberia was then abnormally mild, as now it is abnormally cold.

Although the region extending from North-eastern Siberia to Alaska has been the scene of much tectonic disturbance, and great changes of level have taken place there at a comparatively recent period, it does not appear that Behring Strait was more open during the period in question than at present. On the contrary, remains of the mammoth occur, not only on both sides of the strait, but, as just stated, in the archipelagos also, and such an uprise as would join the latter to the continent, would unite Asia and America, and close the strait altogether.

The comparatively mild climate of these regions during Pleistocene times could not, therefore, have been due to the introduction of currents of warm water from the Pacific into the Polar basin. So we must fall back on the explanation which in the cases before discussed presents the least difficulty, that the arrangement of the areas of high and low pressure, and the consequent direction of the prevalent winds, were then different from those now obtaining.

The severity of the climate of the Liakof Islands and the North Siberian coast during winter is largely due to the southerly and south-westerly winds from the frozen wastes of Central Asia which then prevail there (fig. 4, p. 414). The winter climate of Alaska is also severe, but from a different cause; in the latter country northerly winds from the Polar Sea then prevail. The Mongolian and Manchurian highlands must, I think, have been at least as cold in winter during the Pleistocene Epoch as they are now, if not colder, so that trees could never have flourished in Northern Siberia while the winter winds blew for the most part from a southern or south-

[1] Prof. James Geikie states that a minimum temperature of —94°·6 Fahr. has been registered in this region; see 'Great Ice Age' 3rd ed. (1894) p. 703.

[2] Sir Henry Howorth has expressed the opinion that Siberia enjoyed a more equable as well as a temperate climate during the Mammoth Period, Geol. Mag. 1881, p. 256.

[3] At present there is a difference of more than 80° Fahr. between the average annual temperature of Great Britain and that of the Liakof Islands.

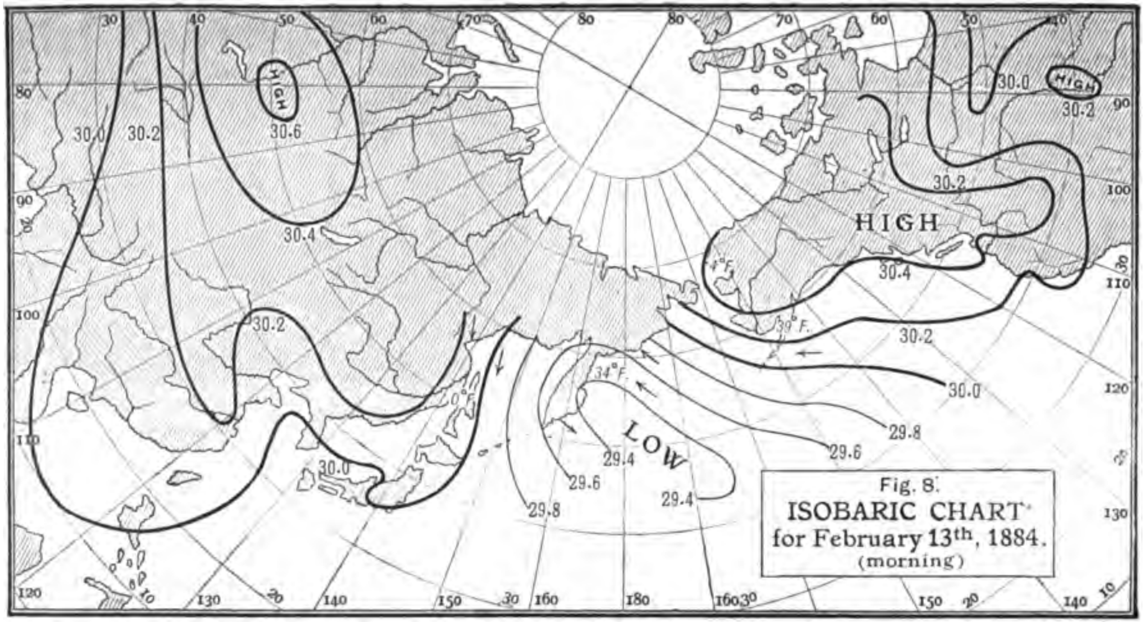
western quarter. To have given the latter country a milder climate at that season, the prevalence of south-easterly winds from the North Pacific would have been necessary, and these could only have occurred when the isobaric lines ran south-east and north-west.

The present meteorological conditions of this region during winter are represented statistically by an elliptical cyclone, lying, to the south of Behring Strait, with its longest axis ranging east and west, wedged in between the high-pressure systems then prevalent over Siberia and North America respectively[1] (fig. 17, p. 450), that of the latter being confluent with the anticyclone of the North Pacific. Such a state of things, however, could hardly have obtained during the existence of an ice-sheet over North America. The centre of the North American anticyclone may then have been farther north, or north-east, in winter (fig. 18, p. 452), while the oceanic area now occupied by the Pacific anticyclone at that season, having a temperature warmer than that over the ice-sheet, would have been prevalently cyclonic.

We have seen above that to produce westerly or south-westerly winds over the Sahara, the anticyclonic system of the Northern Atlantic, a part of which now lies statistically off the western coast of North Africa, must have moved towards the south. I have ventured to show, hypothetically (in fig. 18), how similarly a displacement of the North Pacific anticyclone may have occurred in winter, during the maximum glaciation of North America.

The position of the low-pressure system of the North Pacific at that season varies from day to day, in accordance with the movements of the anticyclones of Siberia and of North America respectively. When the centre of the Asiatic anticyclone advances towards Behring Strait, and that of North America retires eastward, or conversely, the cyclone moves with them eastward or westward as the case may be. The alignment of the latter changes, moreover, with the varying movements of the anticyclones; sometimes it inclines towards the north-west, at others towards the north-east; occasionally it even lies north and south. Fig. 8, p. 425, copied from the Daily Meteorological Bulletins of the United States War Department, shows an example of the former kind. On February 13th, 1884, the centre of the high-pressure system of North America, lying farther north and west than its statistical position in winter (compare fig. 4, p. 414), the cyclone was in consequence situated near the Asiatic coast, with a south-easterly and north-westerly alignment, causing mild south-easterly winds over the Behring Strait region. A temperature of 39° Fahr. was recorded on that date at a point south of the Alaskan peninsula, and 4° Fahr. on the eastern side of the Strait. Ten days later, on February 23rd, these conditions were reversed, as shown in fig. 9, p. 427: the centre of

[1] The rain now caused by the oceanic winds of this low-pressure system does not reach Northern Siberia, but falls on the Pacific coasts of North America, and in Kamtchatka; a shifting of the centre of the cyclone, and a change in its alignment, would, however, have carried the moisture farther north-westward.



[The Behring Strait cyclone lay south-east and north-west, causing south-easterly winds, and comparatively mild weather.]

the Asiatic anticyclone having moved eastward, and that of North America southward, the low-pressure area then lay farther east, and its longest axis ranged south-west and north-east: cold north-easterly winds from the Polar Sea consequently prevailed east of the Strait, and the thermometer fell to -19° Fahr.[1]

As the temporary climate of these regions now changes from day to day under the influence of the winds, so under the more permanent meteorological conditions set up by the existence, during both summer and winter, of the North American ice-sheet, permanent changes of climate in these regions might equally have resulted. If a tongue-shaped area of low pressure similar to that which now extends statistically in January (fig. 17, p. 450) from Labrador to Nova Zembla, but pointing in the opposite direction, had lain in winter during the Pleistocene Epoch to the west of Behring Strait (as shown hypothetically in fig. 18, p. 452), mild winds from the Pacific would have then prevailed along the northern coast of Siberia. Under such circumstances trees might have been able to withstand its winter climate, as now at the North Cape on the same parallel of latitude.

It may be pointed out that, under the conditions suggested in fig. 18, the climate of the area where the east-south-easterly winds prevailed would have been milder than that farther south, on the opposite side of the cyclonic centre, then subject to winds from the north-west, for the same reason that the present climate of Norway is warmer than that of Labrador. In connection with this it is interesting to remember that it is along the Siberian coast, rather than farther inland, that the fossil remains of the mammoth chiefly occur.

The objection may be raised that the mammoth-bearing beds are supposed to belong to a late stage of the Glacial Period, and not to that of the maximum extension of the North American ice-sheet; but it may be pointed out that the peculiar meteorological conditions of the Pleistocene Epoch might have continued in the north-west of the American continent even after much of the ice had disappeared from regions to the south and east.

The effect upon the barometric pressure of a comparatively thin covering of snow and ice, if permanent, would be, in one sense, similar to that of an ice-sheet many thousands of feet thick; that is to say, it would tend to cause conditions anticyclonic as compared with those of the warmer adjoining regions upon which no snow rested. It must be remembered that the direction of the winds depends upon the alignment of the isobars; on the comparative, and not on the absolute, height of the barometer in contiguous areas. The winter climate of a portion of North-western

[1] The climate of this region varies from day to day, in accordance with changes of the wind. Thus 37° Fahr. was registered at the spot named on October 15th, 1883, and 40° Fahr. on the 16th, the wind being from the south-south-east. On the 25th of the same month, the cyclone having moved to the east of the Strait and the wind having changed to the north, the thermometer fell to 23° Fahr., on the 28th to 21° Fahr., and on the 29th to 15° Fahr. On December 10th, it dropped to -21° Fahr., but a few days later rose again, the wind being warmer, to 30° Fahr. on the 18th, and 32° Fahr. on the 19th.

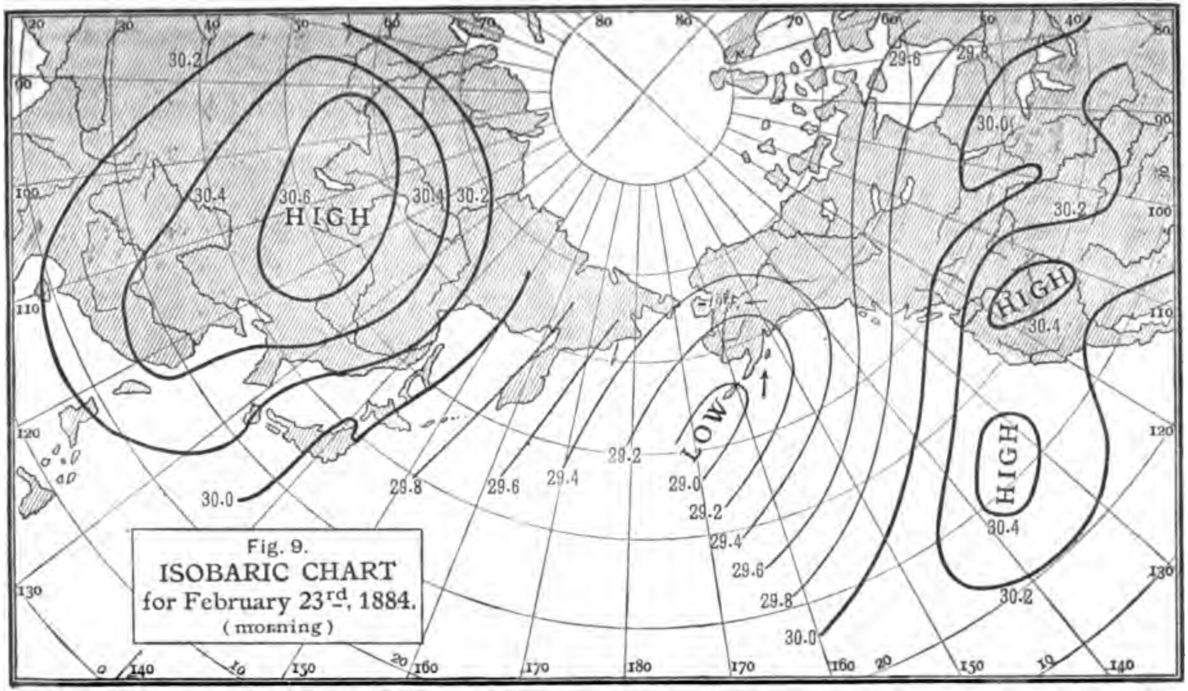


Fig. 9.
ISOBARIC CHART
for February 23rd, 1884.
(morning)

[The cyclone had now moved eastward, and its alignment was altered so that the wind over the Strait was northerly.]
Note.—**The above chart is reproduced from Bull. Int. Meteor. Washington.**

America, moreover, may possibly have been cold at all stages of the Glacial Period: even when the ice-sheet began to break up, masses of melting ice would continue to exist in different districts, so that a cold, and more or less ice-clad area, shrunken indeed in extent, might have persisted in the north-west, possibly for a long time.[1] While this lasted, the relative positions and the alignment of the areas of high and low pressure over the region near Behring Strait, and the direction of the winds resulting, might not have been greatly changed. The time would have come, however, when the influence of the anticyclone of the North American ice-sheet, or of what remained of it, was no longer strong enough to keep the Behring Strait cyclone in the position which I suggest it may have prevalently occupied during the Mammoth Period. It would have eventually swung round to the statistical position that it now occupies, the climate would have become colder, perhaps more or less suddenly, killing off the forests and the elephants alike, possibly during the first winter.[2] Sir Henry Howorth insists strongly on the sudden disappearance of the mammoth, attributing it to floods. Prof. James Geikie suggests the frequent occurrence of blizzards. The third hypothesis, however, that the sudden extermination of mammalian life in this region was due to such a meteorological cause as that here suggested is at least conceivable.

The climate of Alaska during the Pleistocene Epoch seems to have been always milder than that of other parts of North America. There is no evidence of extensive glaciation in that country, but seeing that it forms a peninsula, surrounded on all sides but one by the sea, this cannot have been due to any deficiency of moisture. A distribution of pressure during the glaciation of North America such as that shown in fig. 18 (p. 452) would have brought southerly winds over Alaska, and have prevented any permanent accumulation of snow in the latter country as far as their influence extended. The absence of traces of glaciation in that part of North America which lies west of the Missouri may have also been due to a similar cause.

Some such meteorological conditions as those now existing may have prevailed in the North Pacific area as far back even as the Miocene Epoch. Mr. P. F. Kendall has kindly reminded me that the Miocene floras of Kamtchatka and Japan are of a comparatively

[1] Prof. Chamberlin remarks that 'no one probably doubts the persistence of glaciation [during the Pleistocene Epoch] on the heights of the Cordilleras or in Greenland': quoted in Geikie's 'Great Ice Age' 3rd ed. (1894) p. 772. There does not seem to be any meteorological difficulty in supposing that the ice may have been to some extent permanent in the region west of Hudson Bay, even at the time when milder conditions were prevailing near Toronto.

[2] South-easterly winds could only have prevailed in the Liakof Islands during winter, while the isobars ran in a south-easterly and north-westerly direction; and this could hardly have occurred, unless the centre of the North American anticyclone occupied some such position as that shown in fig. 18 (p. 452).

boreal character.[1] This does not seem, however, to have been due to the existence at that period of cold currents from the Polar seas. Although, according to American geologists, the Behring Strait region stood at a lower level in pre-Miocene times, causing then considerable interchange of water between the Arctic Ocean and the Pacific, this state of things appears to have ceased before the commencement of the Miocene Epoch. The existence at that time of an area of low pressure in the North Pacific would, however, have caused southerly winds in winter, as it now does, with a warm climate on the western coasts of America, and northerly winds and colder conditions in Kamtchatka and Japan.

IV. The Former Existence of Great Lakes in the Basin of Nevada and in Central Asia.

Turning now to the New World, we may remember that American geologists have shown how enormous lakes existed during the Glacial Period in the great basin lying between the Rocky Mountains and the Sierra Nevada, a region at present without outfall, and of extreme aridity. These, to the largest of which the names of Bonneville and Lahontan have been given, have been described by Prof. G. K. Gilbert[2] and Mr. I. C. Russell,[3] of the United States Geological Survey.

Such facts, together with the evidence of more humid conditions in Asia and elsewhere in later Pleistocene times, have given rise to the hypothesis that generally the climate of that epoch was of a pluvial character.[4] While believing that such was the case, I think that pluvial conditions may have been to some extent local. Excessive rainfall occurs at present in many parts of the world, but always locally, and it arises from one cause only, the prevalence of moist and warm winds from the ocean.[5]

The summer rains in India, for example, do not now reach Persia, the climate of which is consequently very dry. The pluvial conditions of the former country at that season, and the arid conditions of the latter, are equally due to the relative position of the areas of high and low pressure of the Asiatic continent and the adjoining

[1] See also E. Kayser's 'Text-book of Comparative Geology' transl. Lake (1893) p. 354.

[2] 'Lake Bonneville' 2nd Ann. Rep. U.S. Geol. Surv. (1881) p. 169.

[3] 'Lake Lahontan' 3rd Ann. Rep. U.S. Geol. Surv. (1882) p. 195.

[4] It may have been during such a pluvial period that the excavation of gorges like the chines of the South of England took place. These, with similar valleys elsewhere, which are out of all proportion to the streams which now flow, or ever could have flowed in them, seem to me to have been caused by sudden and repeated floods of great violence, rather than by the steady and continuous erosion of a time when the rainfall was excessive. Rainfall was no doubt greater, however, in the South of Europe during the Pleistocene Epoch than in the British Isles, as the diluvial deposits of the former region are on a grander scale.

[5] The term 'oceanic climate' is frequently used, but this can only mean a climate influenced by winds blowing from the ocean. The winds could not all have been oceanic at one time, however, during the Pleistocene Epoch.

oceans. It would not be difficult to suggest such an alteration in the alignment of the isobars as would bring oceanic winds over the deserts of Persia, like those which now deluge Burmah and Bengal with rain during the monsoon.[1] It is to such changes (acting locally, I suggest) that the former extension and the subsequent drying-up of the Pleistocene lakes of Utah and Nevada were due.

The succession of events in the region in question, according to Prof. Gilbert[2] and Mr. Russell,[3] was as follows:—a period, previous to the flooding of the plains, with a climate as rainless as that of the present day; afterwards a moist period, during which Lake Lahontan attained a depth of 500 feet, and Lake Bonneville a level 1000 feet higher than that of the Great Salt Lake at present; then a time of desiccation; followed by a return to humid conditions, and finally, by the evaporation of the water to its present level.

During the pre-Lahontan and inter-Lahontan periods, with their arid climate, the distribution of pressure may have been, more or less, similar to that of the present day (figs. 17 & 19, pp. 450 & 454). If, however, the anticylones of the North Pacific and of the North American continent had been shifted from their present positions to those shown in fig. 20 (p. 456), a low-pressure system obtaining statistically at the same time off the western coast of Mexico, similar to that which I suppose may have existed in the Mediterranean area during the pluvial period of the Sahara, more humid conditions would have been caused over the southern and western portions of the United States by warm and moist southerly or south-easterly winds from the Gulf of California, or the Gulf of Mexico. At the present day, a comparatively moist climate in Florida and the regions adjoining it is caused by such winds, but their influence does not extend far north-westward.

These changes in the basin of Nevada, assuming their origin to have been meteorological, may have been due to the presence, at the pluvial stages of the period in question, of an ice-sheet in North America, the pressure of the anticyclone of which disturbed the atmospheric conditions which had existed in the pre-Lahontan period, altering the prevalent direction of the winds, those conditions being re-established when, owing to the disappearance or retreat of the ice, that pressure ceased.[4]

[1] The failure of the monsoon rains to which the last Indian famine was due coincided with an increased rainfall in Mauritius, the Seychelles, Zanzibar, and part of South Africa. An alteration in the relative positions of the centres of high and low pressure diverted at that time the oceanic winds from their usual course, causing them to enrich some regions with moisture at the expense of others.

[2] 'Lake Bonneville' 2nd Ann. Rep. U.S. Geol. Surv. (1881) pp. 172–76.

[3] 'Lake Lahontan' 3rd Ann. Rep. U.S. Geol. Surv. (1882) p. 230.

[4] Mr. Russell not only expresses the opinion generally held by American geologists, that the existence of these lakes was contemporaneous with the Glacial Period, but also that the fluctuations in their water-level indicate changes of climate, the humid periods having coincided with increased cold, and the dry periods with comparative warmth, *op. cit.* p. 231.

The more humid conditions formerly existing in Central Asia (indicated by the greater extension of Lake Baikal), in Tibet, Turkestan, the Han-Hai Basin, and elsewhere, may belong to some stage or stages of the Glacial Period when the relative position of the high- and low-pressure systems, different from that of the present day, favoured the prevalence of moist winds over those regions. These may conceivably have come from the Mediterranean, the Black Sea, or the Caspian, the latter at one period covering a much larger area than it now does. Moreover, the prevalent storm-tracks must have been different during the Pleistocene Epoch from those of our own era.[1] As before stated, a considerable portion of the cyclonic disturbances which approach the continent of Europe from the Atlantic pass to the north or north-west of the British Isles, towards Scandinavia.[2] During the existence of an ice-sheet in those regions, this course would not have been open to them; so far as they continued to travel eastward, they must have done so to the south of the ice-clad region (figs. 21 & 22, pp. 458 & 460). Some of the Atlantic storms do move that way now, but none of them penetrate into Central Asia.

In dealing with the post-Glacial Period, in his valuable work on Prehistoric Europe, Prof. James Geikie calls attention to the alternations of dry or humid, and of cold or mild climates, by which it was characterized. That climatic changes occurred also after the climax of the Great Ice Age need not surprise us. The meteorological disturbances set up during that abnormal and remarkable chapter in geological history may well have continued to exert their influence during the post-Glacial Period. It would not be possible, within the limits of such a paper as this, to attempt to discuss these matters in detail, nor is the necessary information available. It will be sufficient to call attention to the general principle that anomalous weather in the past, even if more or less permanent, may have been due to that which causes temporary changes of a similar character at present, namely, to a change of wind. Even if the cold of the Great Ice Age was due to some extra-telluric cause, it seems hardly necessary to invoke such an origin for the various changes of climate, some of them evidently local, which characterize it, if some simpler explanation can be found.

V. The Meteorological Conditions of the Pleistocene Epoch.

I do not venture to express any opinion as to the cause of the Glacial cold. There was a Glacial Period, and the refrigeration of climate by which it was distinguished had been long coming on, gradually, and apparently without intermission. There is no

[1] See further as to this, § VIII, p. 461.

[2] The low-pressure areas on statistical maps represent, to a considerable extent, the prevalent track of cyclonic storms.

evidence to show that any other part of the Tertiary Era was characterized by marked fluctuations of climate, still less that any Great Ice Age occurred, even during Pliocene times. With the advent of the Pleistocene Epoch, however, an era of climatic disturbance commenced.[1]

It seems to me that it is *a priori* less probable that important alterations of climate, more than once occurring at intervals of a few thousand years only, were due to astronomical or physical causes affecting the whole of the Northern Hemisphere, than that the Glacial and Interglacial deposits of different regions may represent one era only of greater cold, with local changes in the distribution of climatic zones.

It will be urged perhaps that the value of some of the conclusions here arrived at is seriously affected by the fact that geologists are by no means unanimous in their interpretation of the geological record. It is widely believed, to take one example only, by such authorities as Warren Upham,[2] Le Conte,[3] Chamberlin,[4] and others that at a period immediately preceding the Glacial Period, for which the name Ozarkian has been proposed,[5] the North American continent stood at a level greatly higher than that of our own era: the supposed elevation being regarded by the first-named of those writers as the direct, and by Prof. Chamberlin as the indirect, cause of the Glacial cold. Prof. J. W. Spencer believes, moreover, that an elevation of the Antillean region took place in Pleistocene times, which may have reacted upon climate.[6] Prof. Hull argues in a similar way, contending that the Pleistocene elevation which affected America was continuous round the northern and eastern shores of the North Atlantic.[7] Prof. James Geikie, on the other hand, adversely criticizes these views.[8] Some persons may, therefore, feel that until a more approximate consensus of opinion has been attained on these and other points which it is not necessary to mention, it is premature to discuss the meteorology of the Glacial Period at all. There seems, however, sufficient general agreement as to certain facts to justify a preliminary enquiry, it being understood that any conclusions arrived at must be subject to such modifications as may hereafter be necessary.

We may, I think, accept, as a working hypothesis, the view that in the New World there were certain definite centres of ice-accumulation, one in Labrador, another west of Hudson Bay, and

[1] The earliest evidence of this kind in Great Britain is that of the Cromer (so-called) Forest Bed, containing *Elephas meridionalis*, and other mammalian remains preponderatingly southern, together with a temperate flora, which is intercalated between the Weybourn Crag (with the Arctic mollusca, *Astarte borealis* and *Tellina lata*) on the one hand, and the Arctic freshwater-bed (with *Salix polaris* and *Betula nana*) on the other.

[2] Journ. Vict. Inst. vol. xxix (1897) p. 201.

[3] Journ. Geol. Chicago, vol. vii (1899) p. 525.

[4] *Ibid.* p. 667.

[5] Hershey, 'Science' vol. iii (1896) p. 620.

[6] Geol. Mag. 1898, p. 38.

[7] Journ. Vict. Inst. vol. xxxi (1899) p. 141.

[8] *Ibid.* vol. xxvi (1893) p. 221.

a third in British Columbia; that in Europe the ice lay thickest in the Baltic area, crossing the Scandinavian watershed towards Norway, with independent centres of dispersal in the British Isles, in Switzerland, and in other mountain-regions; and further, that the ice travelled outward from these centres to a considerable distance in both hemispheres.[1]

The direction in which the ice-streams travelled may have varied from time to time, but the centres of dispersion were possibly always more or less the same; and this, from a meteorological point of view, is important, since it is upon the position of the centres of the anti-cyclonic or cyclonic systems that the direction of the winds largely depends.

It seems satisfactorily proved, moreover, that the ice-sheets were for a time melted back more than once, if they did not altogether disappear,[2] and that climatic conditions comparatively genial prevailed during the ice-age, locally at least, both in North America and in Europe.

As the form and extension of the ice-sheets varied from time to time, the position of the continental anticyclones would vary also; but so far as the centres of the latter remained the same, their general relation to the low-pressure systems of the Atlantic and the Pacific during the cold periods would be unaltered.

For the purpose of my argument, I propose to take those stages at which, in the eastern and western continents, the ice-sheets are supposed to have attained their greatest development, adopting the views expressed by Prof. James Geikie[3]; and I shall endeavour to trace out what may possibly have been, under such circumstances, the meteorological conditions of the period or periods in question.

It has often been urged that the existence of great ice-sheets must have been accompanied by excessive precipitation. It is clear, of course, that no ice could accumulate, except in regions visited from time to time by oceanic winds. The amount of precipitated moisture necessary to produce permanent glaciation may not, however, have been so great as has been sometimes supposed. When in summer, heavy and sudden downfall takes place, or when in winter, rain is continuous for many days, the streams are flooded, and the greater part of the water which falls is quickly carried out to sea.[4] On the other hand, when the temperature drops below the

[1] The outward travel of the ice-sheets may have been partly due, as Mr. G. W. Lamplugh points out, to the accumulation of snow falling on them, otherwise than at the great ice-centres, Geol. Mag. 1901, p. 142.

[2] Prof. Chamberlin considers (Geikie's 'Great Ice Age' 3rd ed. 1894, p. 769) that the character of the fauna and flora of the Interglacial deposits of Toronto, first described by my friend, Dr. G. J. Hinde, F.R.S., in Canad. Journ. vol. xv (1877) p. 388, points to the existence of milder climatic conditions than those of the present day in the same region.

[3] 'Great Ice Age' 3rd ed. (1894) pl. ix facing p. 437, & pl. xiv facing p. 724.

[4] The loss of water, in this way, from the great ice-sheets would have been, on the contrary, comparatively small.

freezing-point, a comparatively small amount of precipitation, none of which is for the time being lost to the land, may cover the latter with a thick mantle of snow. It is not necessary that snow should fall constantly, or perhaps even very frequently, in order that permanent ice-fields should establish themselves. The prevalent winds blow, for the most part, outward from Greenland, and the yearly precipitation in the centre of that country is probably but small. As a matter of fact, however, sufficient snow does fall there to have produced a great thickness of ice, and the latter can only have been derived from moist oceanic winds occasionally caused by some such an alignment of the isobars as that shown, for example, in fig. 13 (p. 442). We need not suppose, therefore, that westerly winds were prevalent in Scandinavia during the maximum glaciation of Europe, or easterly winds in Labrador during that of North America; but such winds may have—indeed must have—occurred there from time to time. The northern part of the Atlantic area would probably have been at all seasons, during the Pleistocene Epoch, one of atmospheric disturbance, as it is at present in winter: the storms being then, for reasons before given, more violent, and the rainfall more copious. It will not therefore be difficult to understand that, although the prevalent direction of the winds must always have been more or less outward from the ice-sheets, a considerable amount of moisture may have reached these from the ocean. If snow falls faster than it melts or evaporates, it may accumulate, time being given, to almost any extent.[1] The absence of warm winds in summer may be perhaps more necessary for the growth of an ice-sheet than great precipitation.[2]

It will perhaps be pointed out that in Dr. Buchan's maps (figs. 17 & 19, pp. 450 & 454) the alignment of the statistical areas of high and low pressure, and of the isobars, in the Northern Hemisphere, is shown to be generally from south-west to north-east, whereas in my hypothetical restoration of the meteorological conditions of the Glacial Period (figs. 18 & 20, pp. 452 & 456, and 21 & 22, pp. 458 & 460) some of them are represented as pointing from south-east to north-west. Seeing that currents, either oceanic or atmospheric, passing in the Northern Hemisphere from south to north must tend to be deflected eastward, and those flowing from north to south westward, it may be asked whether a prevalent south-east to north-west arrangement of the isobaric lines in former ages is physically probable, or even possible. A reference to the Daily Weather Charts will show, however, that such conditions occur even now not infrequently. When the centre of the Icelandic cyclone lies to the east of

[1] My old friend and master, Searles V. Wood, Jr., in his paper on 'The Cause of the Glacial Period' (Geol. Mag. 1883, p. 296), stated his reasons for believing that the stupendous mass of land-ice under which the glaciated area of North-eastern America was buried may have accumulated under a precipitation less than that which now takes place in the same region.

[2] There must have been more precipitation, however, over the southern parts of the ice-sheets than there is now in Greenland, as the sun's heat in summer, and its melting-power, would have been greater in the former case than in the latter.

Greenland, it may stretch towards the north-east, as shown in the January chart (fig. 17, p. 450). When, on the contrary, it shifts to the west, it often points north-westward. This happened constantly, for example, during the months of September and October, 1881, so that the statistical diagrams for those months show a low-pressure system with a distinct south-easterly and north-westerly alignment, accompanied by the advance of the Asiatic anticyclone towards Scandinavia and the North Sea (see fig. 10, p. 436).

If such a state of things may prevail for a space of two months at present, when generally the conditions are favourable to a contrary arrangement, there does not seem any insuperable difficulty in supposing that, under the altogether different and more permanent circumstances set up by the existence of the great ice-sheets, it might have persisted during a lengthened period.

In attempting to restore the probable distribution of areas of high and low barometric pressure during the Pleistocene Epoch, I found it nearly impossible to do so in such a way as to fulfil what seemed to me to be the necessary meteorological conditions, on the hypothesis that the maximum glaciation of North America and Europe took place at the same time. No such difficulty arose, however, when I adopted the view that the most important glacial and interglacial periods may have been more or less alternate in the eastern and western continents. On my mentioning the matter to Mr. W. N. Shaw, he was kind enough to call my attention to an instructive case of anomalous climate which occurred during the winter of 1898–99. From December to February in those years the weather on the western side of the Atlantic was persistently and abnormally severe, temperatures of from $-40°$ to $-60°$ Fahr. having then been commonly registered in different parts of North America. The excessive cold extended in February as far south as the mouth of the Mississippi: the thermometer falling there to 10° Fahr., the swiftly-flowing rivers of the Southern States were frozen over, and ice was carried out into the Gulf of Mexico. On February 11th, the barometer fell to nearly 28·5 inches in the Atlantic, rising at the same time in Canada to 31·42 inches. For some weeks gales of great violence occurred almost daily in the Atlantic, and in different parts of the North American continent, a wind-velocity of 72 miles an hour being noted in Massachusetts; while in New York Harbour, during a blizzard, one of the great ocean liners, the *Germanic*, sank at her moorings under the weight of the snow and ice which covered her deck and sides. Exceptionally mild weather prevailed at the same period in Western Europe as far east as the Ural Mountains, there having been an entire absence of cold weather in January over Great Britain. Maximum temperatures of 70°·5 Fahr. were recorded in February at Liége (131°·5 above the American minimum of the preceding night), 69° in Paris, and 66° in London. The wave of warm air affected in a similar way the Alpine regions: at Davos Platz, in the South-east of Switzerland, 5000 feet above sea-level, a maximum of 63° Fahr. was reached, the highest previously

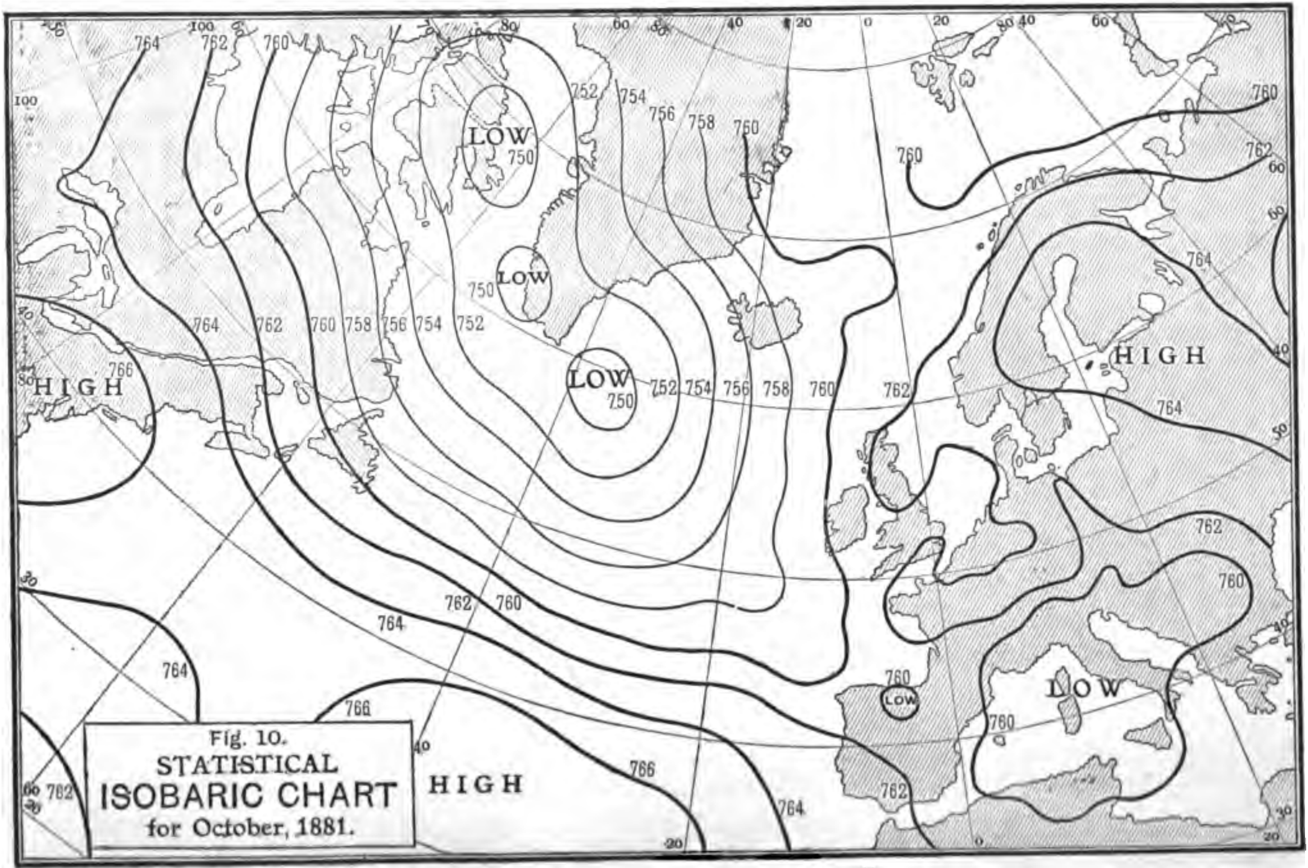
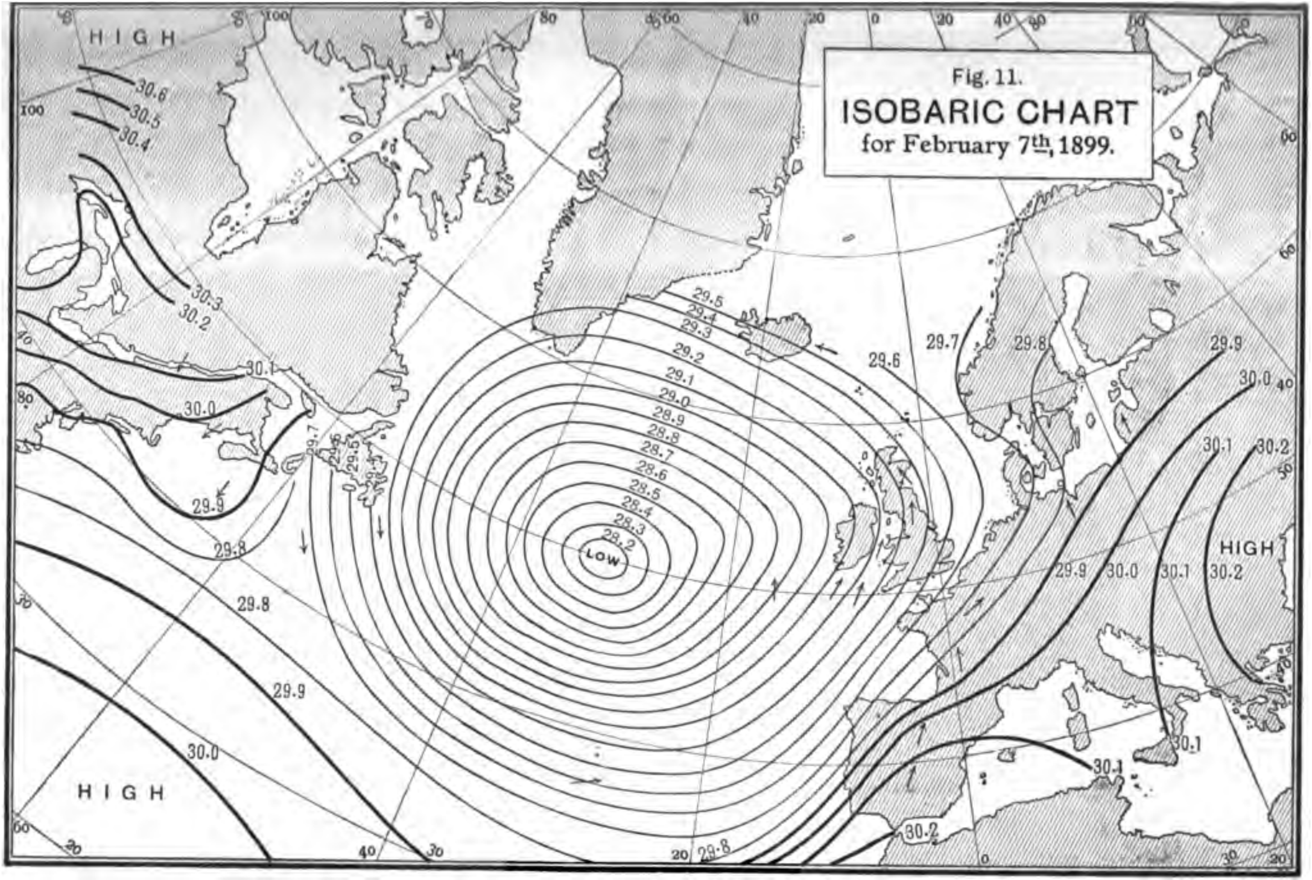


Fig. 10.
STATISTICAL
ISOBARIC CHART
for October, 1881.

[From the 'Tägliche synoptische Wetterkarten.']



[From the 'Bulletin du Nord.']

known temperature at the latter place during February being 52°, and the average maximum 38°.

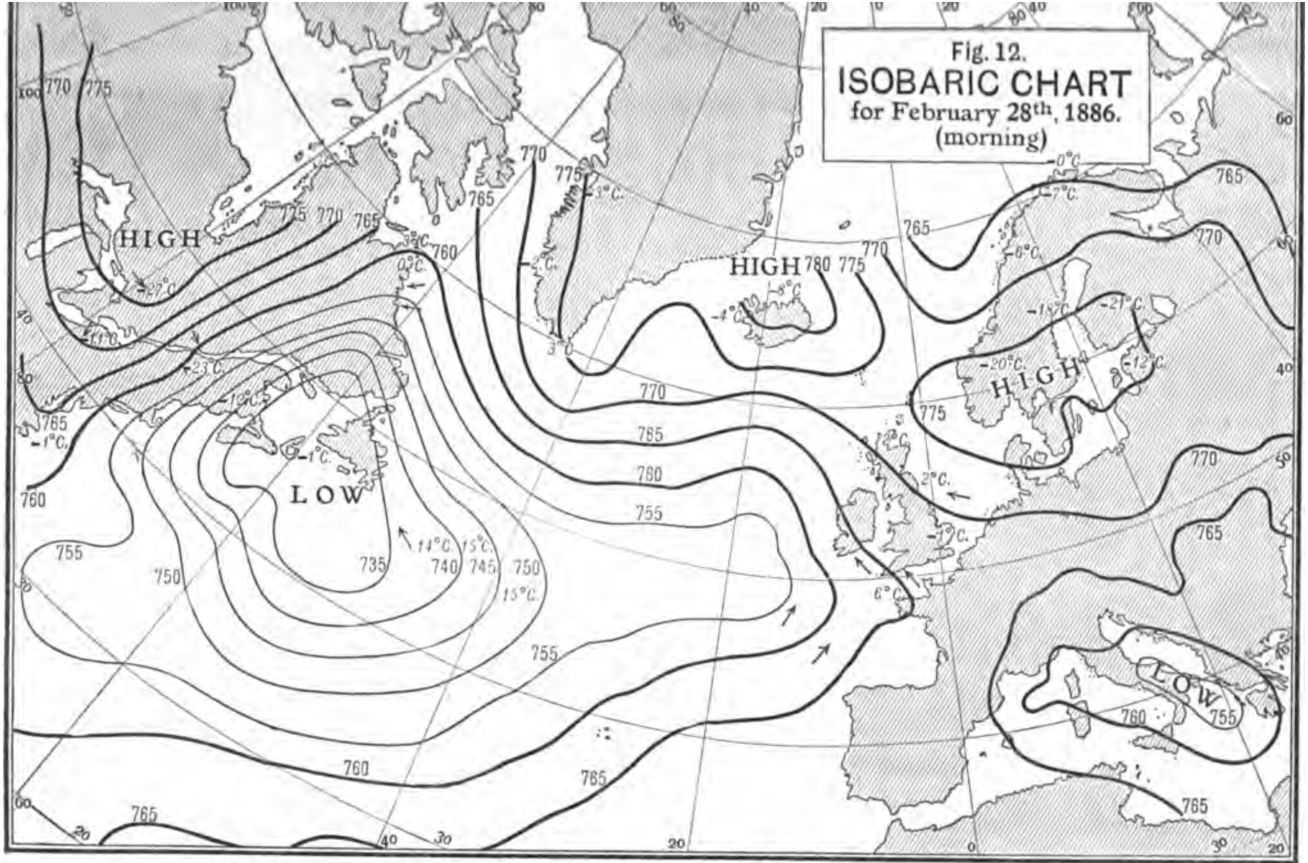
The explanation of these facts is not far to seek. In fig. 11 (p. 437), the isobaric chart for February 7th, 1899, is seen an example of the meteorological conditions of the period in question, which shows that the severity of the winter in North America and its excessive mildness in Europe were alike due to the existence of strongly-marked cyclonic conditions in the North Atlantic. Cold winds were constantly pouring over the western continent from the frozen regions of the north, while southerly winds, strictly complementary to them, were flooding Europe with heated air from the subtropical zone.[1]

Under the meteorological conditions now prevalent (fig. 4, p. 414), the average winter climate of the north-eastern part of the American continent must generally be colder than that of North-western Europe at the same latitude; but the facts just stated seem to indicate that weather unusually mild in the latter may be the necessary accompaniment, and possibly the measure, of extreme cold in the former.

On the other hand, it is not difficult to understand that the existence of an ice-sheet on the eastern side of the Atlantic may not only have been coincident with, but possibly even the cause of, an amelioration of the winter climate of Labrador and New England. When, in winter, Greenland and Scandinavia are anticyclonic at the same time, and the high-pressure system of North America shifts westward, the North Atlantic depression moves westward with it towards the American coast, and when the latter lies sufficiently far south as in fig. 12 (p. 439), the isobaric chart for February 28th, 1886, south-easterly winds are experienced in Labrador. The temperature of the latter region during winter varies greatly from day to day. If the winds blow from Greenland or the Polar regions the weather is very cold, but when they veer to the south or south-east the thermometer rises rapidly. On the day just named, the British Isles, Greenland, and Scandinavia being anticyclonic, a low-pressure area lay in the North Atlantic, near Newfoundland, having a south-easterly and north-westerly alignment. The mild winds arising therefrom caused the temperature of the north-western coast of Labrador to rise to 32° Fahr., 63° higher than that registered at the same spot three days previously, and 42° above the average for the month of February.[2] In Norway and the Gulf of Bothnia at the same time the thermometer stood 36° Fahr. lower than in Labrador, although statistically it should have been 30° higher. Such sudden

[1] A number of charts, illustrative of the facts here stated, were exhibited by the Meteorological Council at the Royal Society's soirée in May, 1900, and the subject was further dealt with by Capt. Campbell-Hepworth, of the Meteorological Office, at the Bradford meeting of the British Association in the same year; see Brit. Assoc. Rep. p. 651.

[2] In the 'Wetterkarten' we find the following morning temperatures on the coast of Labrador:—Feb. 25th, 1886, −34° C. = −29° Fahr.;
Feb. 28th. 1886, 0° C. = +32° Fahr.



[From the 'Tägliche synoptische Wetterkarten.'—Three days previously, the wind blowing from the north-north-west, the temperature of the coast of Labrador was −35° C.]

changes, moreover, are not uncommon; between Feb. 27th and March 7th 1892, for example, the temperature of the coast of Labrador, in lat. 56° north, rose 61° Fahr., owing to the shifting of the wind from north-west to south-east.

The climate of the Northern Hemisphere could not have been wholly cold during any part of the Pleistocene Epoch. Even when the Glacial conditions reached their maximum, regions of comparative warmth must always have been the necessary complement of those lying in the grasp of a perennial winter. On the other hand, it need not have been everywhere warm during the Interglacial episodes; if mild seasons or mild periods were caused by southerly winds in one region, colder conditions would have been produced in others at the same time by winds from the north.

The existence of extensive areas of high pressure, upon which air from the higher regions of the atmosphere is constantly descending, flowing outward from them at a lower level, involves also the existence, in regions more or less contiguous, of areas of low pressure of corresponding importance[1]; reservoirs, in fact, into which the air from the anticyclones may be poured, and from which it may ascend, as by an aerial chimney-shaft, in order to complete the vertical atmospheric circulation. If therefore high-pressure centres existed over the ice-sheets, they would have been necessarily accompanied by low pressure over the adjoining oceans, areas at all seasons, during the Pleistocene Epoch, of comparative warmth and atmospheric humidity.

Statistical maps, such as figs. 4 & 5 (pp. 414 & 415), give an imperfect idea of the meteorological changes going on from day to day. When in winter, for example, the Eurasiatic anticyclone advances westward, and that of North America retreats also to the west, a low-pressure system often exists in Davis Strait, as in fig. 13 (p. 442); when the first-named anticyclone is situated farther north-west, extending from Scandinavia to Greenland, the cyclone lies more to the south[2] (figs. 12 & 14, pp. 439 & 443).

Sometimes an anticyclone stretches from Greenland southward; at others that of the Azores sends out a tongue towards the north (figs. 15 & 16, pp. 446 & 447). In that case, two cyclonic centres are formed, one resting against the American, the other against the European shores. The anticyclone of the Azores seems to be an important factor: generally its centre lies to the east, as in fig. 5 (p. 415), but at times it moves towards the American coast. When the Atlantic is strongly cyclonic, as in fig. 11 (p. 437), the anticyclone seems to be driven southward, but it never disappears entirely; and it must always have been in existence during the

[1] These may be either large and shallow, or smaller with steep gradients, the air ascending more rapidly through the latter.

[2] The statistical chart for January (fig. 4, p. 414) shows the North Atlantic cyclone lying well to the north. As a fact, however, high-pressure conditions frequently exist during winter to the north of it: one or other of the continental anticyclones, and sometimes both of them at once, overspreading Greenland (figs. 14, 15, & 16, pp. 443, 446, & 447).

Glacial Period, forming then, as now, part of the northern subtropical belt of high pressure, the necessary complement of the Equatorial low-pressure trough.

In any case, the general result is that so long as the north-eastern part of the North Atlantic is prevalently cyclonic,[1] so long must southerly and south-westerly winds often occur there, with mild or warm weather over the British Isles. It is only when the influence of such winds is diverted from our shores, and the alignment of the isobars produces northerly or easterly winds, or when Great Britain is anticyclonic, that our winters can be severe. Equally, it seems to me, no great ice-sheet could have originated in Great Britain, and especially in the western part of these islands, while they were under meteorological conditions similar to those now prevalent during winter.

The effect of winds upon the accumulation or melting of snow is well known. In Siberia, for example, the heat of the sun in spring exerts little or no effect upon it, but when, early in June, warm breezes from the south begin to blow, the ground is cleared of its wintry covering, as if by magic, and heated winds 'eat up' the snow everywhere.[2] Prof. James Geikie says, as showing the influence of winds upon climate, that where the flat lands of the Arctic regions are exposed to the northern blasts, the tundras invade the forest-zone, but where they are sheltered from them, the woods encroach on the tundras, so as nearly to reach the shores of the Polar Sea.[3]

The meteorological conditions which may have been prevalent in summer in the North Atlantic during the maximum glaciation of America, resembling to some extent those now prevalent there in winter, would also have been adverse to the accumulation of an ice-sheet in Great Britain. At present the south-westerly winds caused by the Icelandic cyclone may start in winter from a region as far south as the latitude of the Azores, bringing, even in December and January, air sufficiently warm to produce in this country a maximum temperature of from 55° to 60° Fahr.; in summer, similar winds are, of course, considerably warmer.[4] Even in Labrador, and the Hudson Bay region, where the rainfall is as great, and the average winter-temperature as low (from 0° to −20° Fahr.) as in Greenland, the heat in summer is sufficient to prevent the accumulation of a permanent ice-sheet, and such must equally have been the case in Great Britain, I think, under the conditions just stated.

The view that the maximum extension of the ice may have taken place at the same time on both sides of the Atlantic, involves the

[1] This must often have been the case during the maximum glaciation of North America.

[2] See Sir Henry Howorth, 'Glacial Nightmare' vol. ii (1893) p. 389; also A. Russel Wallace, 'Island Life' 2nd ed. (1892) p. 140.

[3] Scot. Geogr. Mag. vol. xiv (1898) p. 282.

[4] The warmth of such cyclones is partly due to the latent heat set free by condensation, but this also is distributed by the action of the winds.

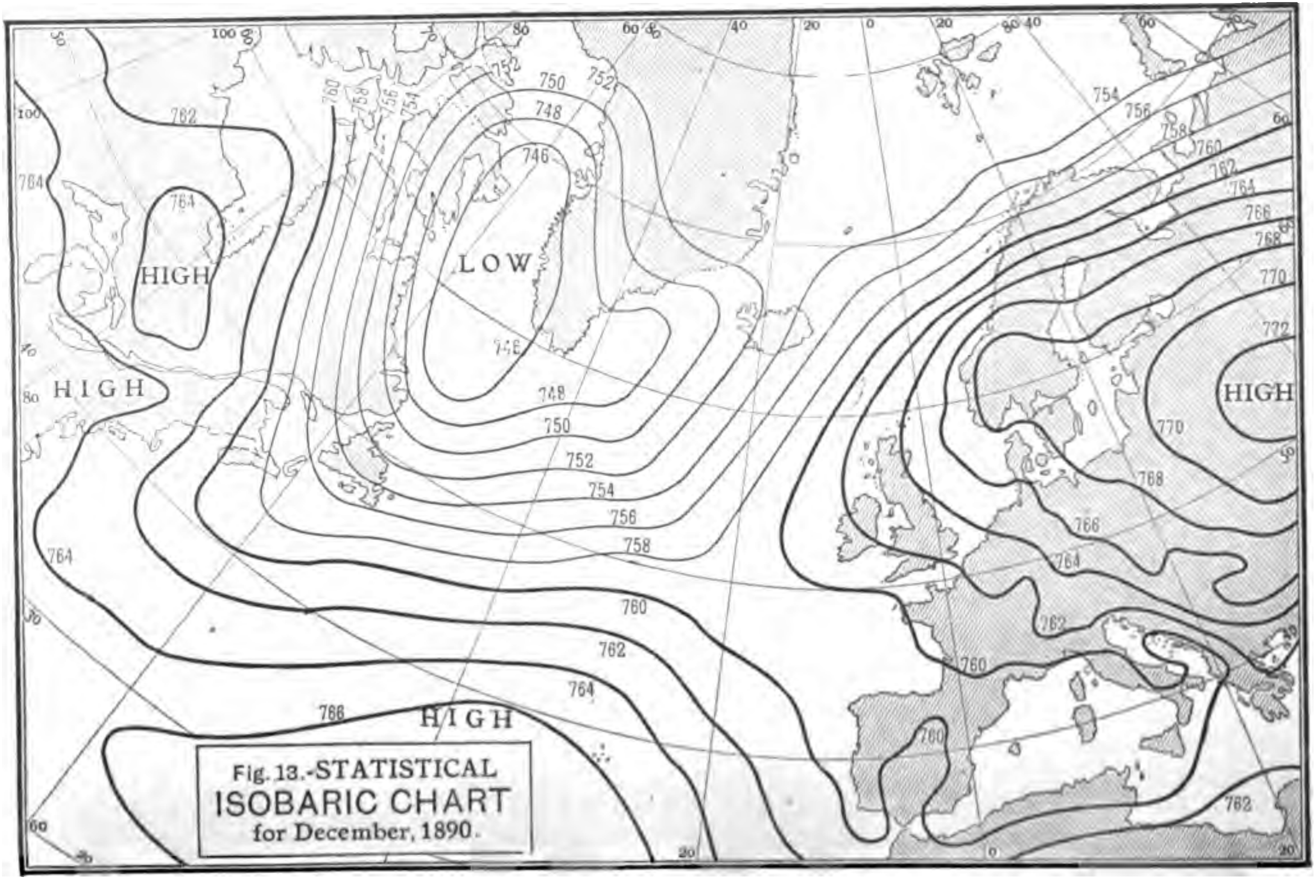


Fig. 13.-STATISTICAL ISOBARIC CHART for December, 1890.

From the 'Tägliche synoptische Wetterkarten.'—Northerly winds prevalent over Labrador, and southerly over Scandinavia and Great Britain.]

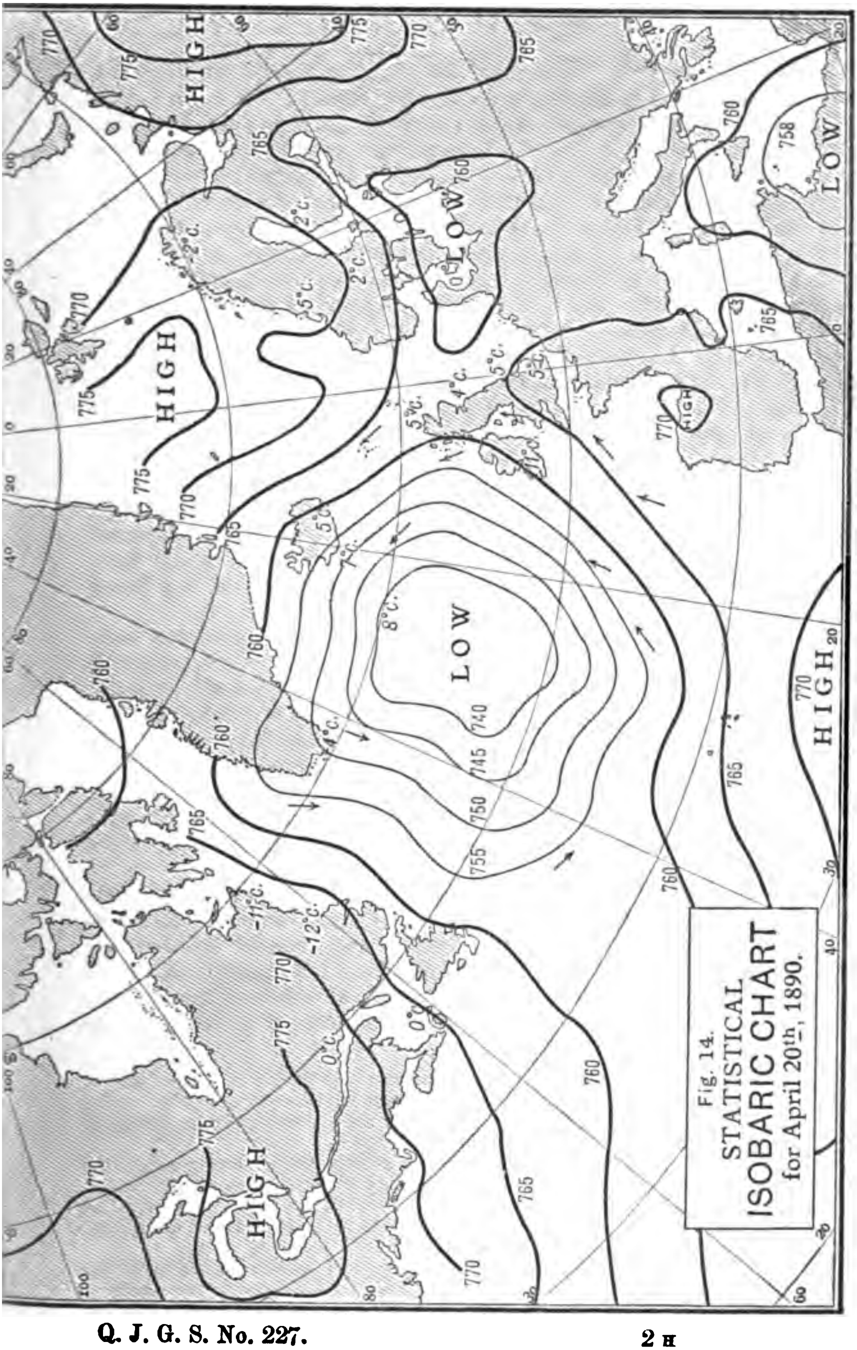


Fig. 14.
STATISTICAL
ISOBARIC CHART
for April 20th, 1890.

[From the 'Tägliche synoptische Wetterkarten.']

admission that the isotherm of 50° Fahr. or thereabouts[1] reached at that period in summer coincidently to lat. 37° 35′ N. in North America, the supposed southern limit of the American ice-sheet, that is, to within 14° of the Tropic of Cancer, where the sun's rays are then vertical, and to about lat. 50° N. in Europe.

The meteorological equilibrium of such a state of things, if even it could have been for a time established, would have been, I think, of a most unstable character. Such a theory requires, however, not that these conditions might have occurred occasionally, but that they should have been persistent for periods extending over thousands of years, which seems to me to be highly improbable.[2] At present it is in winter, when the isotherms are crowded together in North America, that cyclonic storms arise there most frequently. In summer, when the difference in temperature between adjoining regions is not so great, they are less numerous. The marked contrast between the summer climate of the southern part of the American ice-sheet during its greatest extension, and that of the region immediately to the south of it, might have caused (to an even greater extent than now) atmospheric disturbance at that season, and cyclonic storms, with southerly winds to the east of their centres, would have then occurred more frequently in the eastern part of the North Atlantic.[3]

It may, perhaps, be suggested that by the pressure of an anticyclone, extending from the Polar regions over North America, Greenland, and Northern Europe at the same time, the Atlantic cyclone might have been driven so far to the south, that the influence of the south-westerly winds thereby caused, even in summer, although affecting Spain and France, may not have extended to the British Isles. We have seen, however (fig. 11, p. 437), that when the North Atlantic cyclone reaches as far south as lat. 35° N., no such effect is produced, the contrary being rather the case.[4]

The necessary existence in the southern part of the North Atlantic at that time of a high-pressure system, complementary to the Equatorial trough of low pressure, raises the question whether the Icelandic cyclone could have been forced indefinitely southward. The farther it was driven in that direction, moreover, the warmer would have been the winds on the eastern side of its centre. The

[1] The southern coast-line of Greenland now coincides with the isotherm of 45° Fahr. An average summer-temperature in Labrador of 50° Fahr., on the contrary, seems sufficiently high to prevent the permanent accumulation of snow.

[2] The farther southward the isotherms of low temperature reached, the greater, I think, would have been the instability of the atmospheric equilibrium.

[3] Mr. Borchgrevink states that sudden storms of great violence are prevalent near the edge of the Antarctic ice-sheet; see 'First on the Antarctic Continent' 1901, *passim*.

[4] It is the existence of an ice-sheet under such conditions, and especially during the summer, in Great Britain (leaving Scandinavia out of the question), that is the difficulty. No great ice-sheet could have accumulated in a region under the prevalent influence of warm winds.

greater extension of the glaciers of the Alps and of the Pyrenees shows that the climate of those regions also, during the maximum glaciation of Europe, must have been considerably colder than it is at present.

Unless the southerly winds of the North Atlantic had been diverted from the coasts of Europe, I do not see how the British Isles could have been glaciated. On the other hand, if they had been turned prevalently towards Labrador and New England, the climate of that region, in summer at least, could not have been severe.

The view that there may have been such a reduction of the heat of tropical regions in Glacial times as to cause the southerly winds of the North Atlantic to lose their warmth makes, I think, a greater demand upon our imagination than does the hypothesis that I have suggested. The facts that the Swiss glaciers did not invade, to any extent, the great plain of Lombardy, and that there is no evidence of extensive glaciation in the regions bordering the Mediterranean show, however, that the climate of Northern Italy, and generally of the South of Europe, during the Pleistocene Epoch, was not abnormally cold.

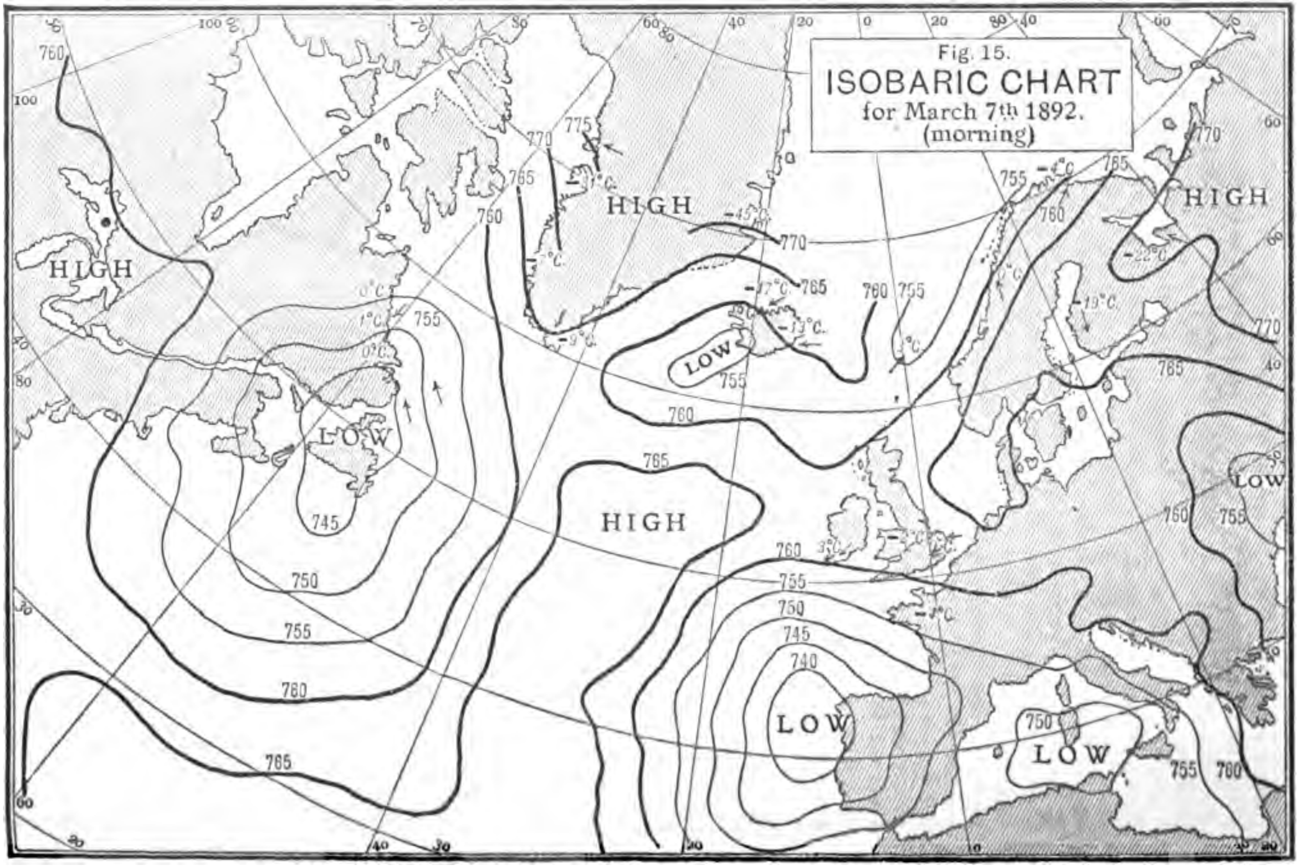
VI. The Meteorological Conditions during the Maximum Glaciation of North America.

Accepting, therefore, as a working hypothesis, the theory that glacial conditions may have been to some extent alternate in the Western Hemisphere with those of comparative warmth in the Eastern, and conversely, we may now endeavour to ascertain the meteorological conditions which in such a case may have obtained in the former region during the above-named stage of the Pleistocene Epoch.

As before stated, the present winter-climate of Labrador and of the region north-west of Hudson Bay (the North American centres of ice-dispersal, according to Prof. Chamberlin)[1] is as severe as that of Greenland. These formerly ice-clad areas lie entirely to the north of the January isotherm of 10° Fahr., while the isotherm of 30° Fahr. for the same month includes nearly all the country supposed to have been covered by the American ice-sheet at the period of its maximum extension (fig. 6, p. 418).[2] Such an ice-sheet might therefore exist at the present day, so far as the winter-conditions of North America are concerned. The summers, however, are hot, almost all the regions supposed to have been ice-clad on the American Continent enjoying in July an average temperature ranging from 50° to 70° Fahr. (fig. 7, p. 419). The temperature varies widely from day to day in Labrador during summer and

[1] See map in Prof. James Geikie's 'Great Ice Age' 3rd ed. (1894) pl. xiv, facing p. 724.

[2] Taking the average for the whole year, we find that the North American ice-centres of the Pleistocene Epoch lie well to the north of the present isotherm of 30° Fahr.



[From the 'Tägliche synoptische Wetterkarten.'—The temperature of Labrador and the Norwegian coast was at this date nearly the same as that of Great Britain, the winds being southerly in the two former areas, and easterly in the last-named.]

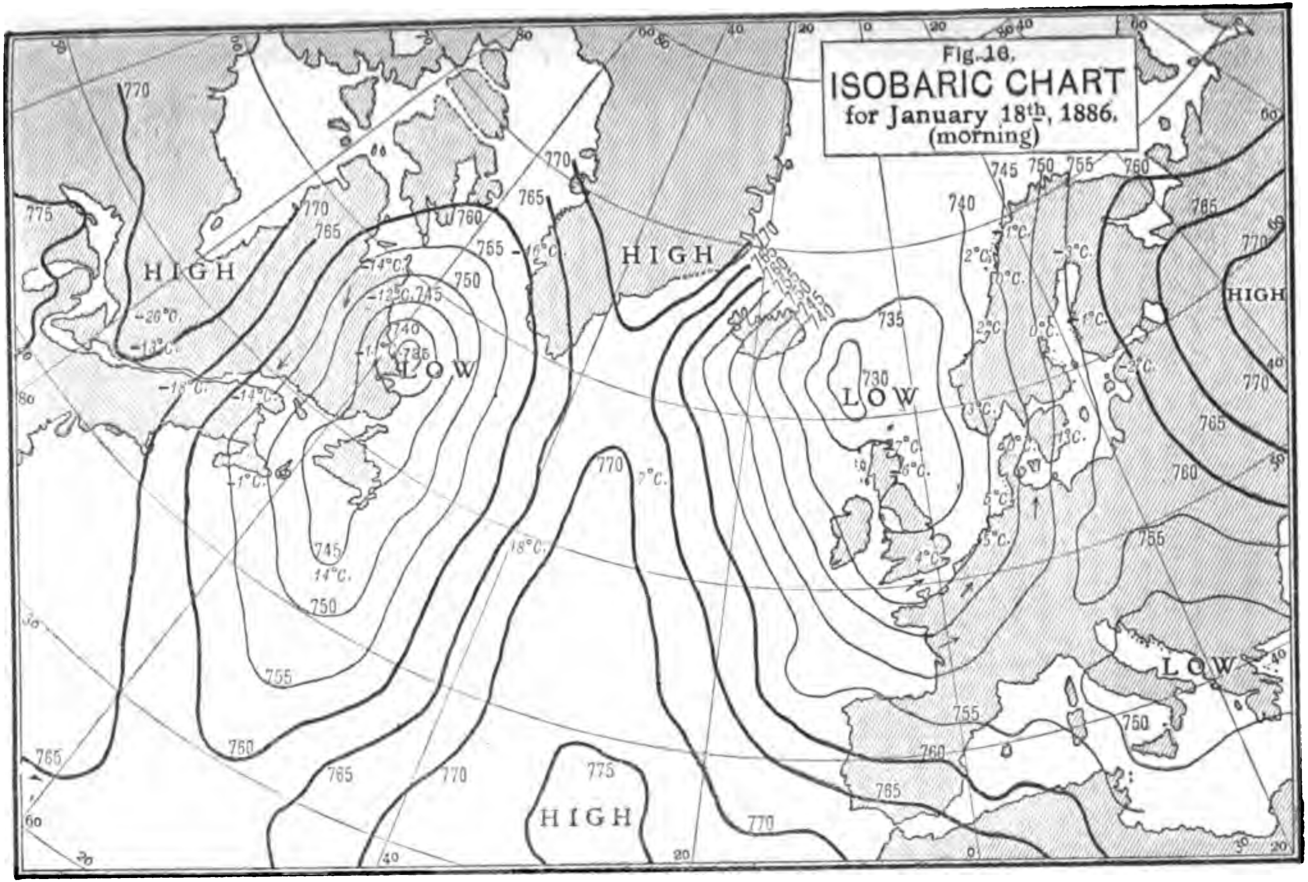


Fig. 16.
ISOBARIC CHART
for January 18th, 1886.
(morning)

[From the 'Tägliche synoptische Wetterkarten.'—A few days later the two cyclones coalesced, and the Atlantic anticyclone moved south-westward.]

autumn, as we have seen it does during winter and spring, the variations being coincident with changes of wind.[1]

It seems therefore to be the influence of the warm winds prevailing intermittently during the summer that now prevents the permanent accumulation of ice in this region; their character being due, so far as they blow from the land and from the south, to the heated state of North America at that season.

When once, however, in consequence of the increasing cold, an ice-sheet had begun to establish itself in North America, the region covered by it would have been protected from such winds. Being anticyclonic, the air would have tended to move outward from it in all directions, as Nansen says is now the case in Greenland.[2] Cold northerly winds would have been prevalent over Labrador and Hudson Bay at all seasons, and the summer-climate of those regions being changed, the causes which now prevent the formation there of a permanent ice-sheet would have been removed.

Under such circumstances, I think, the ice might have gradually crept southward. Moreover, as it did so, the storm-tracks would also have shifted in the same direction. At present, the region between the Great Lakes and Newfoundland is one of much atmospheric disturbance, and it is to the cyclonic storms that are there frequent that the variable climate of Labrador is largely due. As anticyclonic conditions established themselves, more uniform climatic conditions would have prevailed. In this way, the accumulation of the ice might have been self-accelerating.[3]

In figs. 18 & 20 (pp. 452 & 456) I have endeavoured to reproduce the arrangement of areas of high and low pressure which may have been prevalent in winter and summer during the maximum glaciation of North America. For the purposes of comparison I have given also (figs. 17 & 19, pp. 450 & 454) statistical isobaric charts of the Northern Hemisphere for January and July, constructed from those in Bartholomew's 'Atlas of Meteorology'.[4] I have not, however, adopted Mercator's projection (as in figs. 4 & 5, pp. 414 &

[1] The following changes in temperature and in the direction of the wind (2 P.M. local time) took place, for example, in the summer of 1882, at a station in Hudson Strait, on the northern coast of Labrador:—

	Temp.	*Wind.*		*Temp.*	*Wind.*
June 4th	59° Fahr.	S.W.	June 23rd	68° Fahr.	S.W.
5th	37	N.E.	25th	72	W.
11th	55	S.W.	27th	53	N.E.
12th	37	N.E.	28th	75	S.W.
14th	50	W.	July 3rd	53	N.W.
17th	58	S.	8th	47	N.W.
20th	34	N.E.			

[From the synchronous weather-charts of the North Atlantic, published under the authority of the Meteorological Council.]

[2] 'The First Crossing of Greenland' vol. ii (1890) p. 496.

[3] That the growth of an ice-sheet, when once established, would be self-accelerating, was shown by James Croll in 'Climate & Time' 1875, p. 74; and also by Dr. A. R. Wallace in 'Island Life' 2nd ed. (1892) p. 151, by Prof. Chamberlin in Journ. Geol. Chicago, vol. vii (1899) p. 675, and others.

[4] In summer the isobars of 29·90 inches seem rather to group themselves with the high-pressure centres, that of the Polar regions forming a distinct anticyclone, and I have so shown it in figs. 19, 20, & 22 (pp. 454, 456, & 460).

415), as such maps are out of scale for the Polar regions, and do not represent so clearly what I consider may have been the movements of the Arctic high-pressure system during the different phases of the Glacial Period.

It is the oscillation of the centre of this high-pressure system from one side of the Polar Circle to the other during the Glacial Period, changing, as I think it would have done, the statistical alignment of the low-pressure system of the North Atlantic and the direction of the prevalent storm-tracks, which may have to some extent caused, or have been at least coincident with the climatal changes, both of Europe and America.

In constructing these hypothetical diagrams I have reproduced as far as possible the present meteorological conditions, with such alterations only as the former existence of the ice-sheets may obviously have required. I have given the different isobars in full, as in the statistical charts (figs. 17 & 19, pp. 450 & 454), for purposes of comparison only, and because the task of doing so proved a useful check on the work. I do not suppose for a moment that it can be possible to restore in such detail the meteorology of the Glacial Period.

Dealing first with the baric conditions of winter, during the maximum glaciation of North America, and comparing figs. 17 & 18 (pp. 450 & 452), we may assume that the greater part of the Eurasiatic continent was then, as now at that season, an area of high pressure, Central Asia having been probably at least as cold during the Pleistocene Epoch as it is at present. As to America, I have drawn the central part of the anticyclone of that continent (fig. 18) to coincide roughly with what is supposed to have been the greatest southward extension of the ice,[1] and to include Greenland[2] and a part of the Polar Ocean, then perhaps permanently frozen over.[3]

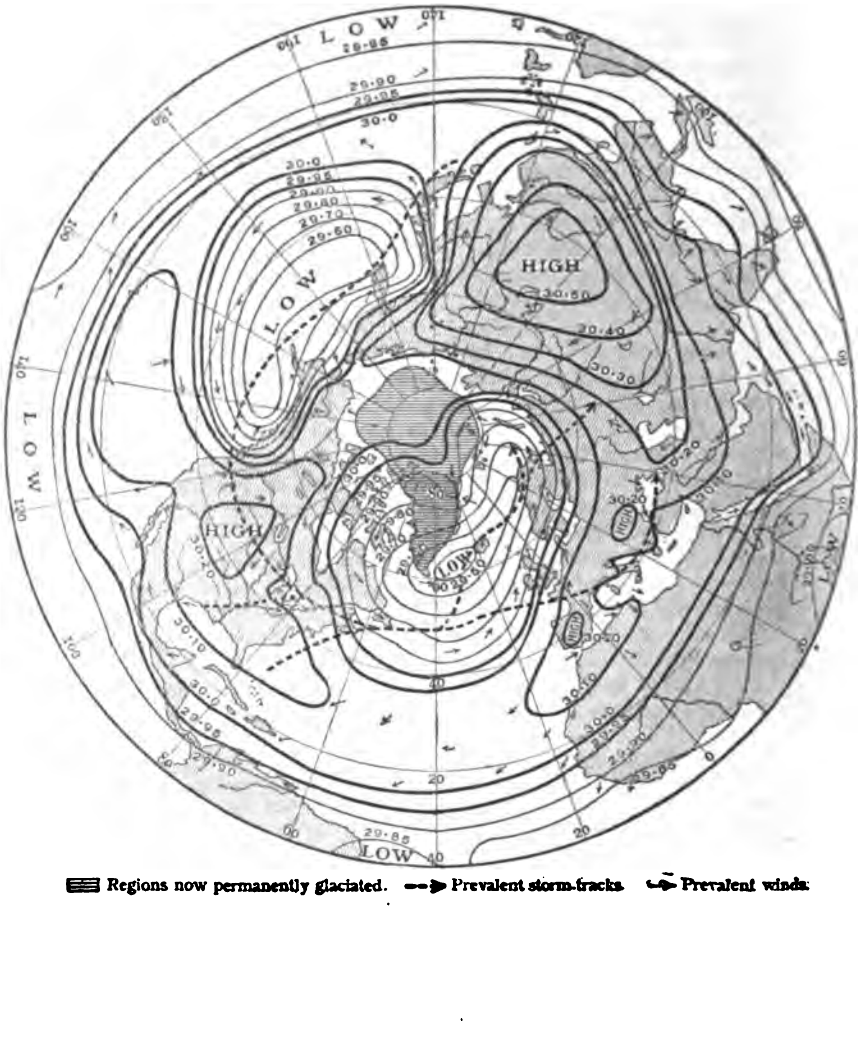
Not only would the actual position and form of this high-pressure system have varied from day to day, however, but it might have been subject also to secular oscillations, and have sometimes extended as far as the northern coasts of Scandinavia. Moreover, every change

[1] See T. C. Chamberlin's map in Geikie's 'Great Ice Age' 3rd ed. (1894) pl. xiv, facing p. 724. It is probable, however, that the anticyclones may not have corresponded so symmetrically with the limits of the great ice-sheets as shown on my charts; but I do not know how otherwise to represent the general relation of the former to the latter.

[2] Greenland may have been during the Glacial Period the pivot, so to speak, upon which the climatal conditions of the Atlantic basin moved, as is the case at present. While the land-tracts, both east and west of it, are now subject to constant changes, the condition of Greenland remains the same, not only at all seasons, but from year to year. It will be seen from my hypothetical charts that on the view taken by me, the winds blowing towards Greenland would have come from a cold quarter during the maximum glaciation both of North America and Europe.

[3] It seems doubtful whether the ice-sheet of Greenland was ever confluent with that of North America; Davis Strait, however, may have been at this period more or less permanently blocked with ice.

Fig. 17.—*Isobaric chart (statistical) for January.*



Regions now permanently glaciated. Prevalent storm-tracks. Prevalent winds.

in the physical conditions of the Glacial Period must have been accompanied by disturbances of the meteorological equilibrium.

As before stated, low-pressure systems would have been prevalent during the winter over the North Pacific and the North Atlantic, but probably with a somewhat different statistical alignment from that of the present day.

The form of cyclones corresponds more or less closely with that of the anticyclones adjoining them. Isobaric lines arrange themselves around centres of high pressure on the one hand and of low pressure on the other, but they represent portions of one system of atmospheric circulation, and must, to a great extent, be roughly parallel one to the other. Hence, if we can ascertain the position and form of the anticyclones at any period, we may form a general idea as to the position and alignment of the cyclones complementary to them, the alignment of the latter being for our present purpose specially important.

The statistical alignment of the North Atlantic cyclone in winter during the maximum glaciation of America (fig. 18, p. 452) may therefore have been of a character similar to that of our own era at the same season, its north-western margin being more or less parallel to that of the American ice-sheet. It may have been situated, however, farther south, because the North American anticyclone would then have been north and north-west of it. South-easterly winds would have been prevalent on the western side of the latter, preventing, together with the cyclonic winds already referred to, the permanent accumulation of ice to the west of the Mississippi and in Alaska.

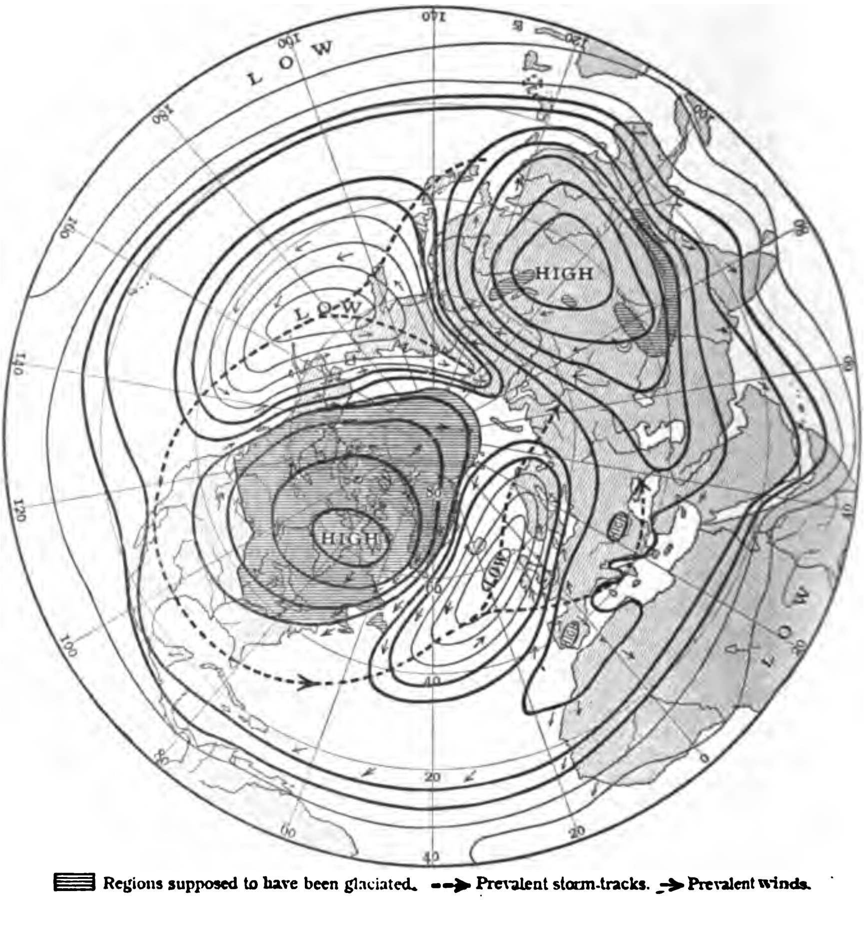
The North Pacific cyclone, with its longest axis parallel to the western edge of the American ice, may have then pointed statistically south-east and north-west, instead of east and west as at present, carrying warm south-easterly winds into that part of the Polar basin which lies west of Behring Strait, and over the northern coasts of Siberia; and such a state of things may have continued until a late stage of the Pleistocene Epoch. This view offers an explanation, as we have seen (§ III, p. 422), of the former abundance of mammalian life in that region.

While, therefore, it is not difficult to understand that the winter-distribution of pressure in the Atlantic during the maximum glaciation of North America may have been of a similar character generally to that of the present day, causing severe seasons in that continent to coincide with milder weather in Europe,[1] it is not so easy to ascertain the baric conditions which may have existed during the summer at the same period. The daily synoptic charts afford us no assistance, since the arrangement of the isobars, which must have then prevailed at that season, is never met with

[1] My hypothetical chart (fig. 18, p. 452), showing the possible distribution of pressure in winter during the maximum glaciation of North America, corresponds closely, as to its general principles, with the isobaric chart for January of the present era (fig. 17, p. 450).

Fig. 18.—*Hypothetical restoration of the relative positions of areas of high and low barometric pressure, and of the prevalent direction of the winds, in the Northern Hemisphere, during the maximum glaciation of North America.*

WINTER.



Regions supposed to have been glaciated. Prevalent storm-tracks. Prevalent winds.

at present. A study of Dr. Buchan's monthly charts shows, however, that as spring advances and the land-tracts of the temperate regions of the Northern Hemisphere are heated by the sun, the continental anticyclones shrink in extent and move northward, finally coalescing over the North Pole as represented in the statistical chart for July (fig. 19, p. 454), and forming there a small anticyclone with a maximum pressure of 29·90 inches only, that of the circumpolar regions as far south as lat. 50° N. being but little lower. At that season, moreover, the isotherms of the northern regions coincide more nearly with the parallels of latitude than they do in winter.

No permanently ice-clad area now exists (except in the southern part of Greenland) south of the present July isotherm of 40° Fahr.[1] The American ice-sheet is believed to have extended, however, considerably beyond the present isotherm of 70° Fahr., and in one direction to have approached that of 80°. (See fig. 5, p. 415.)

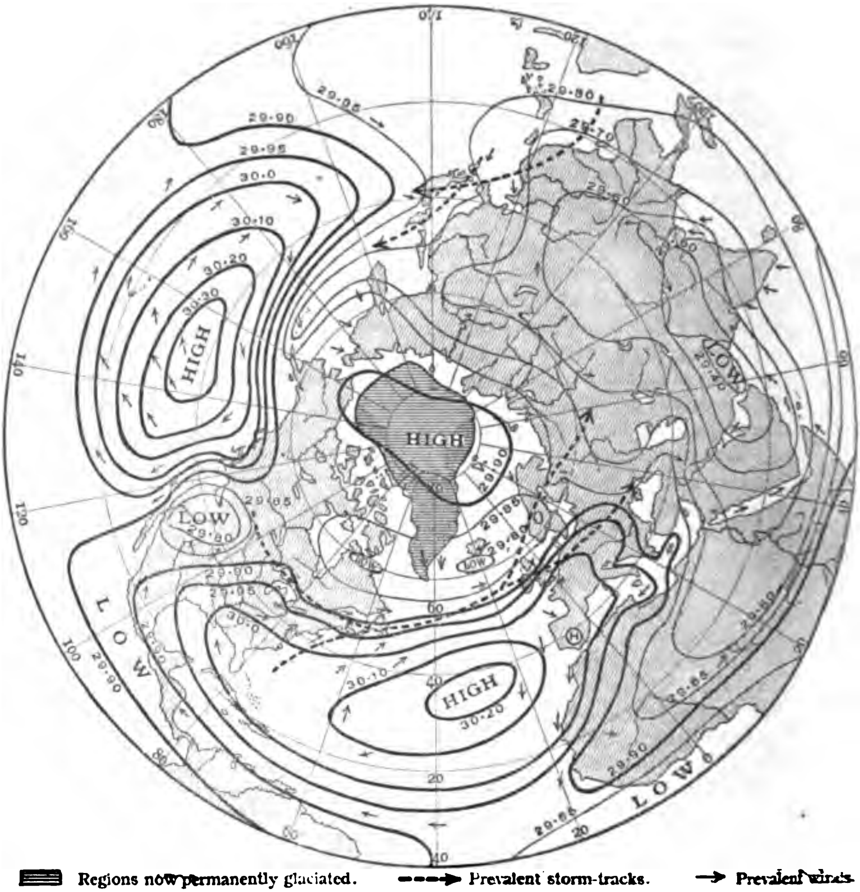
The existence in North America during summer at that stage of the Glacial Period of a cold area of such magnitude so far south must have been accompanied, as already urged, by a distribution of pressure different from that which now prevails. Under such circumstances the Polar anticyclone may have been stronger, and may have reached farther south at that season than it now does. At the same time, pressure over the ice-sheet must have been prevalently higher than that over the adjoining oceans, though the baric gradient may not have been so steep as during the winter. The barometer is not statistically high in Greenland in summer at present, but there is a distinct though gentle gradient of lower pressure from that country towards the south (fig. 19, p. 454), the winds blowing in the same direction as they would do if the pressure were greater all round. While, therefore, during the maximum glaciation of North America there might have been in winter a frequent recurrence of conditions like those described on p. 437 (fig. 11), south-westerly winds may also have been then frequent during the summer on the eastern side of the North Atlantic. If so, the climate of the British Isles would have been warm at that season, and no permanent accumulation of ice could have taken place there. On the other hand, north-easterly winds would have been prevalent during the summer in North America, instead of mild or warm winds as at present.[2]

We have little knowledge as to the conditions obtaining in Central Asia at the different stages of the Glacial Period. There is evidence, however, that at some period the glaciers of the Himalayas and of other mountain-regions on that continent attained a greater exten-

[1] The July isotherm of 45° Fahr. includes the whole of Greenland.

[2] In connection with the suggested anticyclonic condition of the ice-sheet during the summer, it is necessary to remember, as Mr. H. N. Dickson has kindly reminded me, that the air descending upon the anticyclone would have been warmed by compression, and it would therefore have tended to melt the ice. On the other hand, the melting of the ice would have lowered the temperature, as would radiation during the night. Moreover, some of the warmed descending air might have flowed outward at a higher level, without reaching the earth. See Ekholm, Quart. Journ. Roy. Met. Soc. vol. xxvii (1901) p. 23.

Fig. 19.—*Isobaric chart (statistical) for July.*



sion than that of the present day. Prince Kropotkin, quoted by Prof. James Geikie,[1] believes that

'the whole of the upper plateau of Asia and its border-ridges were under a mighty ice-cap.' [2]

Even if such a view may be regarded as extreme, it seems probable that the summer climate of Central Asia may have been sufficiently cold to permit of the existence of permanent snowfields on a more extensive scale than those of the present day.

VII. The Meteorological Conditions during the Maximum Glaciation of Europe and of the British Isles.

While, however, the meteorological conditions of Northern Europe in winter during the maximum glaciation of America may have more or less closely corresponded with those of the present era, the state of things in the North Atlantic basin must have been widely different when the Scandinavian ice invaded the North Sea, leaving its traces far to the south in Holland [3] and elsewhere in Central Europe; when the glaciers of Switzerland and the Pyrenees extended greatly beyond their present limits; and especially when independent centres of ice-dispersion existed in the British Isles.

It is difficult to understand why, when such conditions as those described as possibly obtaining during the glaciation of North America had once established themselves, they did not become permanent, so long as the wave of cold air (to which the glaciation of the Northern Hemisphere was due) continued. If, however, we accept the view that Europe and the British Isles were probably not glaciated contemporaneously with the maximum extension of the ice in North America, we are justified in endeavouring to trace out the meteorological conditions under which ice-sheets could reasonably have existed in the former, even if it is difficult to explain how it came to pass that they extended southward from the Arctic Circle, at one time over the New, and at another over the Old World.

It was shown by James Croll that the direction of oceanic currents corresponds generally with the direction of the prevalent winds,[4] and that the former are largely due to the latter. He further pointed out that an alteration in the direction of the marine currents would affect climate.[5] His view was that, during the Glacial Period,

[1] 'The Great Ice Age' 3rd ed. (1894) p. 697.

[2] [The recent observations of Prof. G. F. Wright, Quart. Journ. Geol. Soc. vol. lvii (1901) pp. 244–50, do not support this view. I have consequently omitted from two of my diagrams a small anticyclone which I had shown as formerly existing during the summer in Central Asia.]

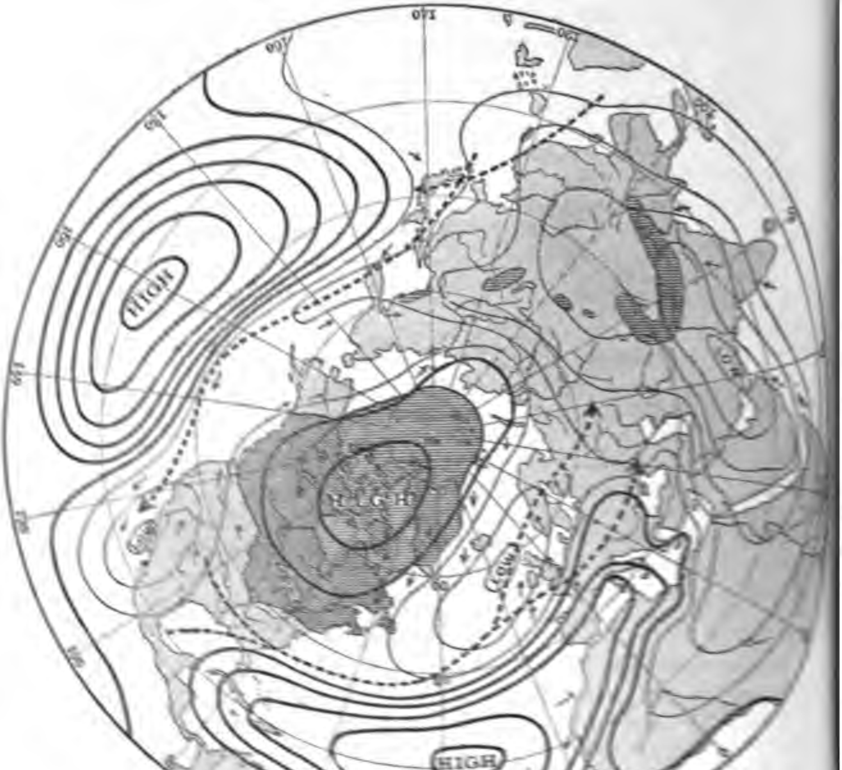
[3] Scandinavian boulders are exceedingly common in some morainic deposits near Utrecht; see Quart. Journ. Geol. Soc. vol. lii (1896) p. 774.

[4] 'Climate & Time' 1875, pl. 1, facing p. 212. In the Bay of Bengal, the Arabian Gulf, and the Chinese Sea, moreover, the local surface-currents vary at different seasons with the changes of the wind.

[5] *Op. cit.* p. 26.

Fig. 20.—*Hypothetical restoration of the relative positions of areas of high and low barometric pressure, and of the prevalent direction of the winds, in the Northern Hemisphere, during the maximum glaciation of North America.*

SUMMER.



a portion of the Gulf Stream now flowing northward from the Equator may have been deflected southward by the agency of winds. Even under such circumstances, I think, an interchange between the Equatorial and Arctic waters must have taken place so long as the channel, 500 miles wide, between Iceland and Great Britain, remained open. Warm currents flowing northward would probably have still hugged the coasts of Europe and have been accompanied, as now, by the frequent recurrence of cyclonic conditions and mild winds in winter over the British Isles, the currents and the winds acting and re-acting on each other.[1] It appears necessary, therefore, to suppose that the Icelando-British Channel must have been closed,[2] either by some elevation of the submarine ridge which stretches, although not continuously, from Iceland to Great Britain, or by ice, or possibly by both causes combined, before a permanent ice-sheet could have accumulated in Great Britain.[3] There does not seem anything intrinsically improbable in this view; indeed, there is evidence to show that such may formerly have been the case. Danish naturalists believe that at some stage during the Glacial Period the depth of the sea between Norway and Iceland was much less than it is at present, the dead shells of shallow-water forms of Arctic mollusca having been dredged there in great abundance from a considerable depth. An elevation of 2000 feet would have created a land-communication between Greenland and Great Britain, while one of half that amount would have restricted the communication between the two seas to a few comparatively narrow channels of moderate depth[4]; these, under such circumstances, might have become wholly or partly blocked by the grounding of icebergs, which can only float in deep water, nine-tenths of their volume being necessarily submerged.[5]

If, however, the Greenlando-British Channel had been closed at that period, a condition of things would have arisen similar to that now existing in the Polar Sea north of Behring Strait.[6] The influx of warm water from the Atlantic having been cut off, the region to the north of the Greenlando-British ridge would have become anticyclonic. The south-westerly winds (the influence of

[1] It seems impossible in these matters to distinguish between cause and effect. Temperature, pressure, winds, and oceanic currents act and re-act on each other as links in an endless chain.

[2] Warm currents from the Atlantic enter the Polar basin to the east only of Iceland.

[3] An additional argument in favour of this view will be found on p. 464.

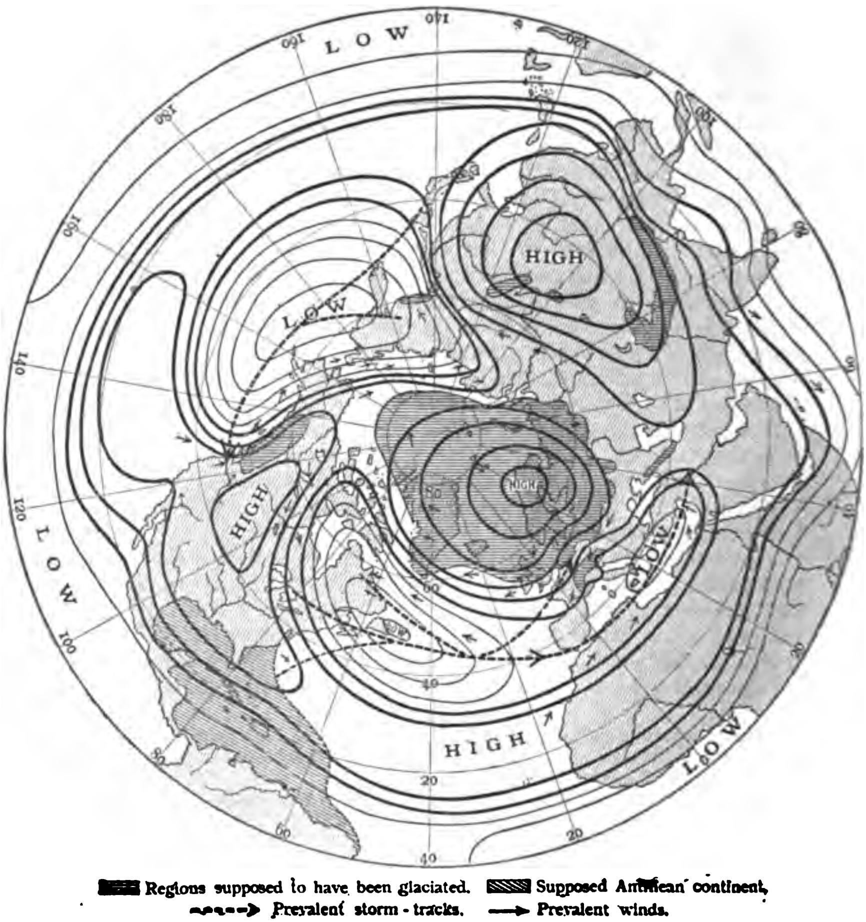
[4] These channels may have been deepened by the scour of currents since the commencement of the Glacial Period. If communication between the Polar Sea and the Atlantic has been cut off and again gradually reopened, this seems more than probable.

[5] Croll estimated that the submerged portion of an iceberg to that above water is as 8·7 : 1; see 'Climate & Time' 1875, p. 384.

[6] Behring Strait is about 36 miles wide at one point, but for the most part considerably more; the amount of water entering the Polar Sea through the strait is not sufficient to influence, either directly or indirectly, the winter-climate of the adjoining regions.

Fig. 21.—*Hypothetical restoration of the relative positions of areas of high and low barometric pressure, and of the prevalent direction of the winds, in the Northern Hemisphere, during the maximum glaciation of Europe.*

WINTER.



Regions supposed to have been glaciated. Supposed Antillean continent.
Prevalent storm-tracks. Prevalent winds.

which now extends as far north as Nova Zembla) being diverted from the shores of North-western Europe, the Arctic Sea, under the colder conditions of the Glacial Period, would have become permanently frozen over, as the Palæocrystic Sea is now[1]; ice-sheets might have formed over the Scandinavian highlands and the British Isles, and high-pressure conditions might have extended thence to Greenland and northward towards the Pole, as shown in figs. 21 & 22 (pp. 458 & 460).

Assuming that the maximum glaciation of the two continents did not take place at the same time, it is necessary to suppose that the ice, and with it the anticyclone of North America, retreated northward (Greenland probably remaining ice-clad), and that coincidently an anticyclone began to spread itself over Europe with the commencement of glacial conditions there. When the ice-sheet had once established itself in Europe, it would have tended, as in the case of America before discussed, to become permanent. Not only would it have been protected at all seasons against warm breezes from the south by its prevalently anticyclonic condition, but such winds would have been diverted from Europe and towards the American coast, because the Atlantic cyclone, no longer able to intrude itself into the Polar basin, would have lain to the south of the Greenlando-Scandinavian anticyclone, its longest axis, parallel to the edge of the Greenlando-European ice-sheet, probably pointing west-north-westward as shown in fig. 21.

The diversion of the prevalent winds of the northern part of the North Atlantic from a south-westerly to a south-easterly direction would have tended, moreover, to divert the Gulf Stream, or what might have remained of it, towards the American coast. Some part of the warm water might possibly under such circumstances have penetrated into Hudson Bay and Baffin Bay, and have ameliorated, concurrently with the south-easterly winds, the climate of the adjoining regions[2]; while another part, having lost a portion of its heat, might have bent round eastward, returning to the south in the form of an eddy along the shores of Western Europe. This would have reduced the temperature of Great Britain, while the possible closing of the channel between Greenland and Iceland might have arrested the Polar current which now affects in a similar way the climate of New England and Labrador.

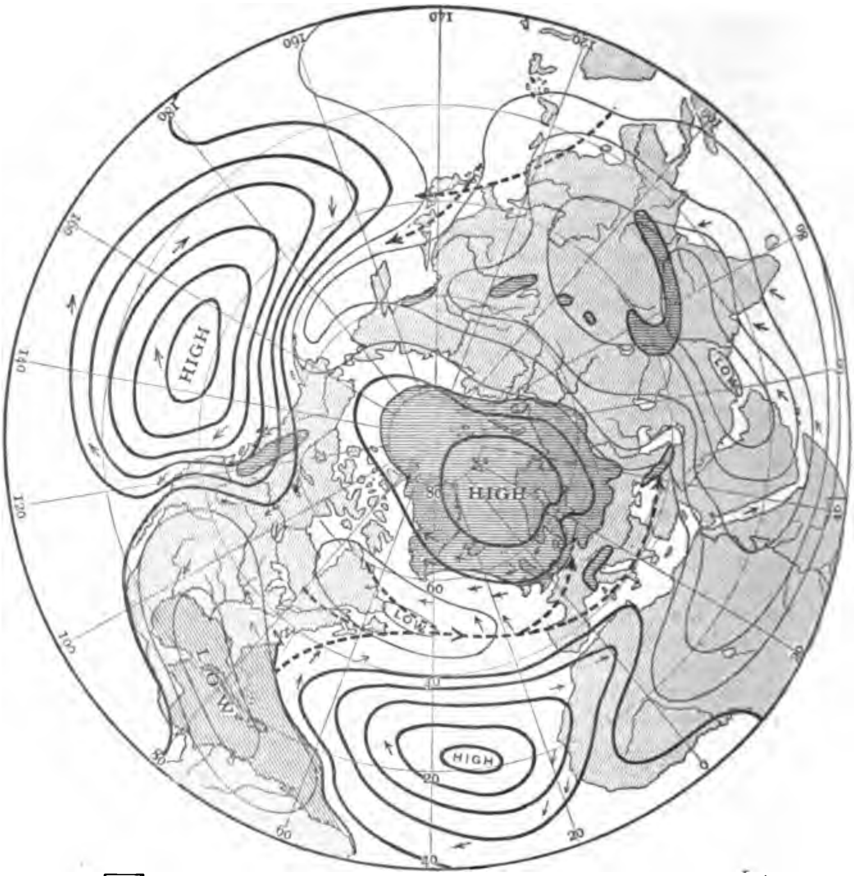
If the anticyclonic conditions existing statistically over Western Europe in October 1881 (fig. 10, p. 436) had been continued north-westward so as to include Greenland, the cyclone shown as lying at that time over Davis Strait would have been driven south-

[1] A similar view has been expressed by Prof. James Geikie and Dr. Buchan; see 'Great Ice Age' 3rd ed. (1894) p. 805.

[2] Croll mentions ('Climate & Time' 1875, p. 261) several cases pointing to the former existence of a mild winter-climate in the extreme north of America at a comparatively recent period (as, for example, in Prince Patrick Island, Banks Land, Wellington Channel, and Melville Island), which may have been due to the existence, at some stage or other of the Pleistocene Epoch, of such a state of things as that here suggested.

Fig. 22.—*Hypothetical restoration of the relative positions of areas of high and low barometric pressure, and of the prevalent direction of the winds, in the Northern Hemisphere, during the maximum glaciation of Europe.*

SUMMER.



Regions supposed to have been glaciated. Supposed Antillean continent.
Prevalent storm-tracks. Prevalent winds.

westward, and a state of things would have arisen closely corresponding with that which I suggest (fig. 21, p. 458) may have obtained in winter during the maximum glaciation of Europe.

In fig. 22, which may be compared with fig. 19 (p. 454), the statistical isobaric chart for July, and with fig. 20 (p. 456), that of summer during the maximum glaciation of North America, I have shown the meteorological conditions of the Northern Hemisphere which may have been prevalent in summer during the greatest extension of the ice-sheet in Europe. If, as seems possible, the Antillean region was then cyclonic[1] at that season, warm oceanic winds would have been prevalent in North America over the southern part of the region covered by ice during the colder epochs of that continent. Interglacial conditions may thus have existed in the Western, coincidently with the maximum glaciation of the Eastern, Hemisphere.

It forms no part of my theory to suppose that minor fluctuations of climate in one hemisphere (like those, for example, referred to in the first footnote on p. 432) were necessarily accompanied by conditions of an opposite character in the other. Cold weather often exists now on both sides of the Atlantic at the same time. It seems to be under circumstances of exceptional intensity that the state of things arises illustrated on p. 437 (fig. 11), when excessive cold in North America coincided with abnormal warmth in Western Europe. Similarly it may have been during the climax of the Glacial Period only that alternate glaciation of the Eastern and Western Continents took place.

VIII. The Prevalent Storm-Tracks of the Pleistocene Epoch.

In figs. 17 & 19 (pp. 450 & 454) I have drawn the prevalent storm-tracks of the present era during winter and summer, according to Dr. Buchan.[2] Originating at the former season in the China Sea, cyclonic storms travel in a north-easterly direction by Japan to Kamtchatka, their course continuing eastward through Behring Sea towards the American coast. Crossing the American continent between 45° and 50° lat. N., the region of prevalent storms passes by the Great Lakes to Newfoundland.[3] Avoiding the Arctic current flowing southward between Greenland and Iceland, and reaching the 40th meridian or thereabouts, some storms move northward, along the western edge of the Gulf Stream, towards Iceland and the North Cape; others take a more southerly course across the British Isles to the Baltic, while some traverse France and Southern Europe to the Black Sea. Storms occasionally pass

[1] As to this, see p. 467.
[2] Bartholomew's 'Atlas of Meteorology' pl. xxix.
[3] An examination of the American synoptic charts shows that some of the cyclonic disturbances of the North Pacific do not cross the Rocky Mountains. Others frequently arise, however, at the same time in similar latitudes, to the east of that range.

eastward in winter into Siberia, penetrating at times even to long. 90° E., but as a rule they die out when they reach the Ural or the Caucasus Mountains, and the anticyclonic regions of Asia.

The course of cyclonic storms seems to depend upon the daily or seasonal variations in the position of anticyclonic systems. In April, for example, when the winter-anticyclone of North America moves northward, and extends to the north of the Icelandic cyclone, pressing the latter southward, the prevalent storm-tracks no longer approach Iceland, but are situated farther south than in winter. In July, moreover (fig. 19, p. 454), although storms originate in the China Sea, as indeed they do all the year round, they do not cross the North Pacific, that region being then anticyclonic. Other storms, however, arise in North America and in the North Atlantic, and some of them invade Europe. A few penetrate into Asia at that season, but as a rule they die out, as in winter, when reaching the Urals, or the Caucasus. For a great part of the year the prevalent storm-tracks of the North Atlantic nearly coincide with the statistical isobars of 29·90 and 29·95 inches, as shown in the chart for July (fig. 19, p. 454), that is, with the division between the high and low-pressure systems. Although cyclonic storms, when once started, traverse high latitudes, sometimes even crossing to the north of the 70th parallel, they originate for the most part in regions farther south. Occasionally, however, they arise as far north as lat. 60° N., as, for example, in Behring Strait.[1]

Applying these considerations to the meteorology of the Pleistocene Epoch, it will not be impossible, I think, so far as my hypothetical charts may represent correctly the general isobaric conditions which then obtained, to arrive at a reasonable idea as to the regions in which storms may have been prevalent at the different stages of that epoch.

Referring first to fig. 18 (p. 452), the isobaric chart for winter during the maximum glaciation of North America, storms may have arisen then in the China Sea, as they do now, and have crossed the Pacific towards America, but so long as they continued to travel eastward, they must have passed to the south of the anticyclone of the American ice-sheet, the stronger contrast between the climatic zones of that period coinciding with atmospheric disturbances of a strongly-pronounced character. Storms crossing the Atlantic might then have often hurled themselves with much violence against the western shores of Europe and the British Isles, and preceded always, as they must have been, by southerly and south-westerly winds, would have tended to ameliorate the climate of those regions.[2] Possibly their eastward progress may have been arrested then, as at present, by mountain-ranges.

[1] See Maps of storm-tracks, Bull. Int. Met. Washington.

[2] Cyclonic storms would, I think, have continued their prevalent north-easterly track from the Atlantic towards Lapland, as at present, so long as the Icelando-British Channel remained open, and warm currents flowed northward along the shores of Scandinavia and the British Isles.

During the maximum glaciation of Europe, storms may have passed in winter from Japan to Kamtchatka, across Behring Sea, while others traversed North America; but those which crossed the Atlantic towards Europe must have more often than at present taken a south-easterly course (fig. 21, p. 458). In this way, as we have seen, a humid climate may have been caused in the Sahara.

The great extension of the Swiss glaciers during the Pleistocene Epoch shows that a considerable amount of moisture must have reached them from the ocean, some doubtless from the west. Cyclonic storms, possibly of small diameter, travelling eastward from the Atlantic, as suggested in fig. 22 (p. 460), may have then occurred in South-western Europe from time to time.

The climate of the region north of the Swiss massif was colder at this period than that to the south of it, the former having been more or less under the influence of the anticyclonic winds proceeding from the ice-sheet of Northern Europe. While ice was accumulating from age to age in the north, and the great glacier of the Rhone Valley was piling up its moraine against the flanks of the Jura, the sun's heat on the southern slopes of the ice-clad mountains during summer, and the rains which may have there fallen, produced floods of incredible violence, which have covered the lowlands of Piedmont and Lombardy, from the foot of the Alps to the Adriatic, with a thick and continuous sheet of diluvial gravel and mud.[1] It is only when standing on the tower of the Cathedral at Milan, or on the summit of the Superga, near Turin, looking across the great plain towards the distant mountains rising abruptly from it, that one can realize the strength and volume of the torrents which must have issued from the Alpine valleys at this epoch.

The Pleistocene deposits of Northern Italy here mentioned are believed by Italian geologists[2] to belong to the Saharien zone of Meyer, that is, to a period contemporaneous with the humid condition of the desert region of Northern Africa, and of the great extension of the Swiss glaciers. This view harmonizes with the meteorological conditions suggested in figs. 21 & 22 (pp. 458 & 460).

To the same period has been referred part of the vast sheet of coarse detritus, often containing blocks of large size, which extends northward from the foot of the Pyrenees to the Garonne, and thence to Bordeaux, and also the gravels of the Rhone delta and of the valley of the Var,[3] as well as the enormous sheet of gravel which covers the plains of Hungary. The inundations by which these deposits were caused can only have occurred during the prevalence of atmospheric disturbances of far greater intensity than those of our own era.

[1] On the contrary, the snow-line descends much lower on the southern than on the northern slopes of the Himalayas, moist winds reaching that region from the former quarter only.

[2] For much interesting information as to the Pleistocene deposits of Southern Europe I am indebted to my good friends, M. G. F. Dollfus, of Paris, and Prof. Sacco, of Turin.

[3] As to the latter, see Chambrun de Rosemont's 'Etudes Géol. sur le Var & le Rhône' Nice, 1873. The former have been described by many observers.

Floods of great violence must also have been prevalent in Northern Italy and elsewhere in Southern Europe during the Miocene Epoch. I noticed, during a recent visit, in the coarse Miocene conglomerates (Aquitano) of the Superga, an enormous waterworn block, measuring at least 12×6 feet. In Prof. Sacco's opinion, the Miocene Epoch was characterized by alternations of periods of tranquillity and of great floods. Some meteorological explanation of these recurring atmospheric disturbances may hereafter be found.

Referring now to the prevalent storm-tracks of North-western Europe during its period of maximum glaciation, the fact that the accumulation of ice was greater in the Baltic region than in Norway indicates that the cyclonic disturbances from the Atlantic, by which the necessary humidity was supplied, did not cross the latter country, else precipitation would have been greater on the Norwegian highlands than in Sweden, as it is at present.[1] Moisture must therefore have reached Scandinavia from the south-west, possibly as shown in figs. 21 & 22 (pp. 458 & 460), the cyclones moving towards the Baltic along the region lying between the *mer de glace* of Great Britain and that of Switzerland. This view supports, I think, that suggested on p. 457, that during the maximum glaciation of Europe the Icelando-Scandinavian channel was closed, an anticyclone then existing prevalently in that region, by which the passage of cyclones from the North Atlantic to the North Cape was more or less barred.

IX. A Possible Explanation of the Secular Movements of the Ice-Sheets, and of the Polar Anticyclone, during the Pleistocene Epoch.

It will be less difficult, I fear, to show that glacial periods in one hemisphere may have coincided with milder conditions in the other, than to offer a satisfactory explanation of the way in which such changes of climate may have been brought about. As Huxley once observed, however, there are two kinds of difficulty: that of which we cannot at once find the solution, and that which knocks us down altogether; and our present difficulty is of the first class. Moreover, if the theory now proposed is rejected, we are confronted by what seems to me the still greater difficulty of accepting the opposite view.

The present meteorological condition of the temperate regions of the Northern Hemisphere is that of unstable equilibrium, characterized by never-ceasing change. We observe and register the daily and seasonal movements of the isobaric curves to which the variations of the weather are due, but we cannot trace the ultimate

[1] The average annual rainfall on the western coast of Norway is very heavy, amounting at Bergen to 73 inches. In Sweden it is low: 21 inches, for example, at Upsala. See Bartholomew's 'Atlas of Meteorology' p. 20.

causes of those movements. Nevertheless, we know that any important meteorological disturbance at one point, however produced, may affect, in a greater or less degree, the atmospheric conditions in regions far removed from it, so that the initiation of secular movements of the Polar anticyclone during the Glacial Period may have arisen at some distant point, or in some unsuspected manner.[1]

It seems, however, that any permanent shifting of the Polar anticyclone which may have taken place during the period in question (possibly not of a more serious character than that which occurs from time to time at present) must have followed rather than have preceded the suggested transference of the ice from one side of the Atlantic to the other.

The existence of an ice-sheet in either hemisphere must have produced more or less permanence in the climatic conditions of the regions under its influence, so that changes in the relative position of areas of high and low pressure would have been of a temporary character, tending always to revert to the normal. It seems necessary, therefore, to suppose that it was by the means of some outside disturbing force that alterations in the position of the ice-sheet were initiated. Unless that force were extra-telluric, or some such as that suggested by Prof. Chamberlin (mentioned below), the hypothesis which attributes climatic changes to tectonic movements of subsidence and elevation seems to offer the best explanation of the difficulty.

The view that the Pleistocene Epoch was one of epeirogenic disturbance is held on both sides of the Atlantic. The late Prof. Le Conte believed that the eastern part of the North American Continent stood during the Ozarkian Period (already referred to) from 3,000 to 5,000 feet at least above its present level, and it is to this he attributed the glaciation of that region.[2] Prof. Chamberlin adopts Le Conte's view, although he considers that the glacial refrigeration was not so much due to this cause directly, as indirectly, through its effect on the amount of carbon-dioxide in the atmosphere. American geologists trace, moreover, at a later stage in the Glacial history, that of the Champlain deposits, a great subsidence, affecting principally the eastern and northern portions of the continent. The apparent connection between glaciation and subsidence has also been pointed out by Prof. James Geikie,[3] who has adduced many cases of alterations in level during the Pleistocene Epoch.

In both the New and the Old World, therefore, we have evidence of upheaval on the one hand and subsidence on the other, during various stages of the Glacial Period. We can in some measure establish, locally, the sequence of these tectonic changes; but there may have been other oscillations of level, especially such as may

[1] Prof. Fairchild remarks: 'The various elements affecting climate, geographic, atmospheric, and astronomic, are thought to be so nicely balanced, that a comparatively slight change or maladjustment may produce serious climatic effects.' Proc. Amer. Assoc. Adv. Sci. vol. xlvii (1898) p. 271.

[2] Journ. Geol. Chicago, vol. vii (1899) pp. 527 *et seqq.*

[3] 'Great Ice Age' 3rd ed. (1894) pp. 606, 794, etc.

have given the land-tracts an elevation greater than that of the present day, of which we have no evidence.

In the earth-movements of the Glacial Period, we may possibly have a *causa vera*, or possibly one of the *causæ*, which (admitting the view here taken to be correct) induced the shifting of climatic zones. Epeirogenic changes, whether of upheaval or depression, must have altered the distribution of pressure, and the consequent direction of the prevalent winds, thus varying or limiting the areas within which the great ice-sheets could have existed.

It has been sometimes assumed that movements, either of upheaval or subsidence, would have similarly affected different parts of the Northern Hemisphere at the same time: that, for example, elevation and extension of the land occurred simultaneously in North America and in Central America on the one hand, and in Greenland, Scandinavia, and the British Isles on the other.[1] It seems at least possible, however, that the rising of one area may have coincided with the sinking of another, and such earth-movements were probably of an irregular or complicated nature. Changes of level in adjoining regions, during past epochs, have not always been of an uniform character.[2] The researches of American geologists, especially, show that unequal movements of the earth's crust were characteristic, in the Western Continent, of the Glacial Period.

The case mentioned in one of my former papers, where the elevation of the southern portion of the Anglo-Belgian Basin, in Pliocene and Pleistocene times, coincided with a great subsidence to the north, may also be mentioned.[3] Moreover, the ice seems to have moved, as to its general course, both in Europe and America, in different directions at different periods, and this may not improbably have been due to differential earth-movements.[4]

Such an elevation of the North American continent as that postulated by Le Conte would have lowered its temperature, and so have favoured the accumulation of ice upon it; but alterations of level in outside areas might also have affected the climate of the regions in which glaciation took place.

Accepting, for the purpose of argument, Prof. J. W. Spencer's view as to the Pleistocene elevation of the Antillean region, a

[1] See, for example, Hull, Journ. Vict. Inst. vol. xxx (1898) p. 305.

[2] Prof. James Geikie says that, at one stage of the Glacial Period, a depression which reached only 130 feet in Scotland attained 880 feet in Scandinavia. Deposits containing northern shells are found at levels in North America successively higher as we trace them northward, namely at 200 feet in New England, 560 feet at Montreal, 1000 to 1500 feet in Labrador, and 1000 to 2000 feet in the Arctic Regions; see 'Great Ice Age' 3rd ed. (1894) pp. 780–81.

[3] Quart. Journ. Geol. Soc. vol. lii (1896) p. 748.

[4] It may perhaps be worthy of notice that, both in Scandinavia and North America, basin-shaped depressions now exist near regions where, during the Glacial Period, the ice lay thickest. Local changes in the movement of the ice may, however, have been sometimes due to other causes.

continental land-tract, the eastern margin of which is supposed to have lain to the north-east of the West Indies, as shown by a dotted line in fig. 21 (p. 458), would seem to have existed at some stage of the Glacial Period over what is now the Gulf of Mexico. This region, under the influence of the vertical rays of the sun in summer, must have been then very hot (with an average temperature of possibly 80° Fahr.), and would therefore have been cyclonic, instead of anticyclonic at that season as at present. But such conditions would have caused a prevalence of heated south-easterly winds over the southern part of the United States, as shown in fig. 22 (p. 460), which would have rendered the existence of an ice-sheet in North America as far south as lat. 37° 35′ N. (its supposed maximum extension) impossible.

Let it be assumed that a gradual elevation of the Antillean region coincided with subsidence in Labrador, the North American continent having moved from south to north as on a pivot, as did the Anglo-Belgian Basin in Pliocene and Pleistocene times: ice would then have accumulated more slowly in the north, while, at the same time, it would have been melted back in the south. If, further, the depression of Labrador had been contemporaneous with an elevation of Scandinavia and the British Isles,[1] and especially of the Icelando-British ridge, an ice-sheet might have begun to form on the Scandinavian highlands, coincidently with the shrinking of the ice in North America. In the struggle between the anticyclones of the Old and New Worlds, similar to that which goes on during the winter at the present day, but attended with more permanent results, the anticyclone of the Eastern Continent might thus have gained the ascendency, and the statistical alignment of the low-pressure system of the Atlantic might have been altered from south-west and north-east to north-west and south-east, changing the prevalent direction of the warmer winds, and diverting them, together with the oceanic surface-currents, from the coasts of Europe to those of America. Under such circumstances, the ice-sheets of Eastern North America might have gradually diminished, and have finally disappeared, while at the same time glacial conditions established themselves in Europe.

The fact that the cyclonic system of the North Atlantic, just referred to, now maintains statistically a south-westerly and north-easterly alignment, causing the prevalence of winters comparatively mild in Great Britain, and severe in Labrador, seems to indicate that the influence of the North American anticyclone, other things being equal, may always have been stronger than that of Europe. This being so, the former might have been able after a time, assisted

[1] Prof. Bonney believes that an uplift of Great Britain and Scandinavia would have been necessary, in order to make the existence of an ice-sheet possible in those countries; see 'Ice-Work' 1896, p. 277. Dr. A. R. Wallace argues also, that high land is necessary for the initiation of a glacial period, 'Island Life' 2nd ed. (1892) p. 134.

perhaps by meteorological changes arising, directly or indirectly, from tectonic disturbances in Europe or America,[1] or possibly in Asia, to have regained its ascendancy, restoring the earlier state of things, though not perhaps to so great an extent as at first. Secular changes in climate arising from causes like these may thus have taken place during the Glacial and post-Glacial Periods, gradually diminishing in intensity, until the exciting cause of the increased cold, whatever it may have been, had finally passed away.

Glacial conditions seem to have existed during one stage or another of the Pleistocene Epoch in the Southern Hemisphere, as in Australia, New Zealand, and South America, due, it is supposed by some authorities, to changes in the relative levels of land and sea. Such changes must necessarily have been attended by disturbances of the baric equilibrium, and in the direction of the prevalent winds, and the influence of the former may have been felt even in the Northern Hemisphere.[2]

When we consider the complicated character of the laws affecting the atmospheric circulation, it is not difficult to understand that in this way, or in others which it is not necessary to indicate, meteorological disturbances may have been set up, the influence and extent of which it is impossible to determine.

The hypothetical charts illustrating this paper are intended to represent the conditions which may have obtained at two stages only of the Pleistocene Epoch—namely, those of the maximum extension of the ice in North America, and in Europe, respectively. Almost any number of other meteorological combinations may, therefore, have existed from time to time during that era. If all the facts were before us, the geology and the meteorology of the Glacial Period would necessarily prove to be in exact accordance. At present our information is but scanty, and the palæometeorologist must work with the best material that he can obtain, content with the enunciation of general principles, and with the solution of some of the more simple problems presented to him.

In deprecation of the criticism that this paper is of a highly speculative character, I may perhaps urge that it is not the first of its kind on the climate-question. The length which it has attained, much greater than I originally intended, must serve as my excuse that I have been able to treat this many-sided subject, which is clearly of great difficulty, from one standpoint merely, and, I fear, in a somewhat superficial manner. The views here stated are offered in a suggestive, and not in a dogmatic, spirit, and the

[1] Prof. J. W. Spencer believes that movements of subsidence and elevation took place more than once in the Antillean region during the post-Pliocene Epoch.

[2] The opinion has been expressed that some of the climatic changes of the Glacial Period were more or less sudden; see, for example, Warren Upham, Journ. Vict. Inst. vol. xxix (1897) p. 201. Changes in the weather are proverbially so; the latter arise, as I suggest the former may have done, from variations in the direction of the winds.

most that I can hope for is to have shown a *prima-facie* case for further investigation. My desire is to call the attention, especially of meteorological experts, among whom I have no pretension to rank, to a neglected, interesting, and possibly important branch of enquiry.[1]

I desire especially to acknowledge my great indebtedness to Mr. W. N. Shaw, F.R.S., who has not only permitted me to make constant use of the valuable library at the Meteorological Office, but has been kind enough to discuss the subject with me on more than one occasion, and to give me the benefit of his experience and of some important suggestions; and also to Dr. A. Buchan, F.R.S., and Mr. J. G. Bartholomew, F.R.S.E., for their courtesy in allowing me to copy maps from the 'Atlas of Meteorology.' My best thanks are due, moreover, to Mr. H. N. Dickson, F.R.S.E., from whom I have received some friendly and valuable criticism, and to Prof. James Geikie, F.R.S., and others from whose writings I have largely borrowed.

X. Summary.

The winds are an important factor in determining the distribution of climatic zones. Deviations of the monthly or yearly isotherms from the normal are coincident generally with the direction of the prevalent winds.

The influence of marine currents upon climate is indirect rather than direct. Winds and currents, however, act and react on each other.

Changes of wind cause marked and sudden changes in the weather: daily, as in Great Britain, or seasonally, as in India; though the general direction of oceanic currents remains more or less the same. Permanent alterations in climate would also have resulted during past epochs, had the course of the prevalent winds been permanently changed.

The winds blow in a direction more or less parallel to the isobars; the latter group themselves round centres of high and low pressure, the higher pressure being, in the Northern Hemisphere, to the right of a man standing with his back to the wind.

Anomalous weather is due to some unusual arrangement of the areas of high and low barometric pressure. Similarly, former cases of anomalous climate can only have occurred when the meteorological conditions were favourable.

At present, the continental areas are hotter than the ocean during summer, and are therefore cyclonic; they are colder in winter, and are then anticyclonic. Cyclones and anticyclones are necessarily mutually complementary, as are the troughs and crests of waves. The baric conditions of the oceans at different seasons

[1] Among the services which palæometeorology may hereafter render to the geologist, not the least perhaps may be that of assisting him to determine the chronological relations of geological zones in different regions where no direct evidence bearing on the subject may be attainable.

are usually of a more or less opposite character to those of the neighbouring land-tracts.

During the Glacial Period, the regions covered by ice might have been, to a greater or less extent, anticyclonic at all seasons, low-pressure systems prevailing at the same time over the warmer regions immediately to the south of them and over the adjoining oceans. The relative positions of areas of high and low barometric pressure, the direction of the prevalent winds, and the consequent distribution of climatic zones, would in such a case have differed from those of the present time: oceanic winds, with copious rainfall, may have prevailed over regions now arid, and mild winters where they are now excessively severe.

The teachings of geology will thus throw light on the meteorology of the past, and meteorology may explain the causes of former cases of anomalous climate.

At present, for example, dead shells are but seldom found on the eastern shores of Norfolk and Suffolk, though they are constantly driven on to the Dutch coast by westerly gales. The extraordinary profusion of such débris in the Upper Crag-beds of East Anglia, the littoral deposits of the North Sea in Pliocene times, suggests that easterly gales were more common there at that period than they are now.

The prevalence of strong westerly winds in that region at present is due to the fact that the centres of cyclonic storms approaching Great Britain from the Atlantic, pass to the north or north-west. When an anticyclone exists to the north, which is not often the case during the winter, cyclones take a more southerly course, and easterly gales are experienced in the Crag district. Such a state of things existed, not improbably, in the later Pliocene Epoch, as glacial conditions may have by that time established themselves, to a greater extent than at present, upon the Scandinavian highlands.

During the existence of anticyclonic conditions over the European ice-sheet at the period of its maximum extension, when lower pressures prevailed in the warmer areas south of it, cyclonic storms may have passed farther south than they do at present, bringing oceanic winds over the Saharan desert, which, it is known, formerly enjoyed a more humid climate.

The abundance of the mammoth in Pleistocene times along the shores of the Polar Sea (where no trees can grow at present, owing to the excessive severity of its winter-climate), may have occurred during the existence of an ice-sheet in North America, when a different statistical alignment of the Behring Strait cyclone, due to the more northerly position of the American anticyclone at that period, brought mild south-easterly winds from the Pacific over Northern Siberia, ameliorating its winter-climate, just as the prevalent alignment of the Icelandic cyclone now carries mild south-westerly winds over Great Britain and Scandinavia, and thence into the Polar regions at that season.

The alternate humidity and desiccation, during the Pleistocene Epoch, of the now arid basin of Nevada, where great lakes formerly

existed, may have coincided with successive alternations in the alignment of the isobars, caused by the advance or retreat of the American ice-sheet, originating at one time moist oceanic, and at another dry winds from the land, over the region in question.

It is difficult, however, to restore hypothetically the meteorological conditions of the Pleistocene Epoch, on the theory that the maximum glaciation of the Eastern and Western Continents was contemporaneous. At present the influence of the Gulf Stream and the south-westerly winds indirectly caused by it carries a comparatively warm climate northward during the winter over the British Isles and Scandinavia into the Polar Circle, but no permanent ice-sheet could have existed in those countries under such circumstances. The view that the maximum glaciation of North America and Europe was contemporaneous, involves the admission that an enormous anticyclone extended more or less prevalently at that epoch from the Pole southward over a considerable portion of both continents at the same time, during the winter, and to some extent in summer. Such a state of things, however, if even it could have been for a time established, would have been meteorologically of a most unstable character, tending to produce at all seasons atmospheric disturbance in the Atlantic, with prevalent southerly and south-westerly winds to the east of the cyclonic centres, flooding North-western Europe with warmth. Conditions similar to those which may have prevailed during the maximum glaciation of North America occurred during the winter of 1898–99, when the weather was persistently and excessively cold in America, and abnormally warm in Europe; temperatures of $-60°$ Fahr. were recorded on the same day in the one, and $70{\cdot}5°$ Fahr. in the other; the former being due to cold winds from the Polar regions, and the latter to warm winds from the subtropical zone, strictly complementary to them, and due to the same cause.

The northerly winds on the one side, either of a cyclonic or an anticyclonic centre, are the necessary equivalent of the southerly winds on the other. It is not possible, therefore, that the Northern Hemisphere could have been wholly cold at one stage of the Glacial Period, or wholly mild at another. The alignment of the isotherms and the distribution of climatic zones was probably at least as irregular then as at present, arctic and temperate conditions coexisting in different areas at the same latitude. Indeed, if the disturbances of the atmospheric equilibrium in temperate regions were more marked at that period, as seems probable, the contrasts in climate may have then been even greater than they are now.

No such meteorological difficulties arise if we adopt the hypothesis that the more important Glacial and Interglacial variations of climate may have alternated in the Western and Eastern Continents. Minor changes, however, may have been of more local distribution.

The winter-temperature of Labrador (one of the North American centres of ice-accumulation during the Glacial Period) is as cold, and the annual rainfall as great, as in Greenland at the present day;

the summers are, however, warm in the former, owing to the southerly winds which there prevail intermittently at that season. Were it not for this, Labrador might even now resume its glaciated condition.

The accumulation of an ice-sheet in North America would not necessarily have prevented Western Europe from enjoying a climate as temperate as that of the present time; it might even have raised the winter-temperature of the latter region. On the other hand, it seems probable that the effect of the anticyclone of an ice-sheet, extending eastward from Greenland, over Great Britain, Scandinavia, and Northern Europe, would have been to change the prevalent alignment of the low-pressure system of the North Atlantic, producing warm south-easterly winds in Labrador and New England during the winter, instead of the northerly winds now prevalent there. The alteration in the direction of the winds would have tended, moreover, to divert the warm surface-currents of the North Atlantic from the European to the American coast.

The maximum glaciation of Great Britain could only have taken place at a time when the Icelando-British channel was closed, either by an elevation of the submarine ridge connecting those countries, or by its being blocked with ice; or perhaps under the influence of both causes combined. There is evidence to shew that alterations in the level of this region did occur during the Glacial Period. It is possibly to differential earth-movements of elevation and subsidence in different parts of the Northern Hemisphere that the suggested shifting of glacial conditions from one side of the Atlantic to the other may have been due.

The views here taken afford a simpler explanation of the geological facts than those usually adopted. Instead of supposing that the climatic changes of the Great Ice Age, several times recurrent at intervals of a few thousand years only, were due to astronomical or extra-telluric causes, it is suggested that the average temperature of the Northern Hemisphere during the Pleistocene Epoch being, from some hitherto unexplained cause, lower than that of our own era, conditions of comparative warmth or cold may have been more or less local, as they now are, and that the more important variations of climate during that epoch may have affected the great continental areas at different periods.

XI. Appendix.

Two important communications, to which it is necessary briefly to refer, have recently appeared on the climate question: one from Prof. T. C. Chamberlin, of Chicago,[1] the other from Dr. Nils Ekholm, of Stockholm.[2] The first I had not seen when, in September 1900, I submitted to the Meeting of the British Association, at Bradford,

[1] Journ. Geol. Chicago, vol. vii (1899) pp. 545, 667, & 751.
[2] Quart. Journ. Roy. Met. Soc. vol. xxvii (1901) p. 1.

an abstract of the present paper; and the second had not then appeared.

These writers adopt the view, not only that the more important changes of climate during past ages, such as that, for example, which is supposed to have occurred between the Carboniferous and the Permian, were due to variations in the amount of carbon-dioxide in the atmosphere, but also that to some extent the minor climatal oscillations of the Glacial Period may be traced to the same cause. Such an alteration in the atmospheric constitution must have been, however (as Prof. Chamberlin points out), of general and not of local operation, and the hypothesis that the latter group of events was so caused is inconsistent with that suggested by me that the maximum glaciation of one region may have been contemporaneous with the existence of genial conditions in another, situated in a similar latitude.

It does not follow, however, that because the carbon-dioxide theory may account for the climatal change at the end of the Palæozoic Era just named, or for the long and gradual refrigeration which went on, apparently without intermission, during the Miocene,[1] and until the end of the Pliocene, as well as for the general rise in temperature which has taken place since the end of the Glacial Period, that it must necessarily have been the cause of all, or even part of, the marked, repeated, and possibly sudden changes which, commencing at the close of the Pliocene, continued during the Glacial and apparently, though with less intensity, during the post-Glacial Period.[2]

I cannot help doubting whether the suggested alterations in the constitution of the atmosphere could have been sufficiently rapid in operation to have originated the latter. Dr. Ekholm, indeed, remarks (*op. cit.* p. 26), dealing with the gradual reduction of temperature in Miocene times, that

> 'the temperate Polar climate of that age, with its slowly-proceeding deterioration, may have occurred during a rate of carbonic acid not much greater perhaps than the present one, the cooling influence of a slow decrease of carbonic acid exhibiting its full strength only much later.'

Prof. Chamberlin points out that the reduction of the thermal absorption of the atmosphere during the Ice Age consequent on a deficiency of carbon-dioxide, would have intensified the difference in temperature between the Equatorial and Polar regions, and between that of the land and of the sea,[3] and Dr. Ekholm expresses a somewhat similar opinion.[4] This, however, would have tended to produce, under the special circumstances of the Glacial Period, increased

[1] The fossil mollusca of the various Miocene horizons of the Mediterranean region, for example, show, in Prof. Sacco's opinion, no indication of alternations of climate.

[2] Prof. Chamberlin indeed believes that some of the less important climatic changes of the Glacial Period may have been due to variations in the atmospheric circulation, Journ. Geol. Chicago, vol. vii (1899) p. 772.

[3] *Ibid.* p. 555. [4] Quart. Journ. Roy. Met. Soc. vol. xxvii (1901) p. 24.

atmospheric disturbance in the Atlantic, and a distribution of climatic zones even more irregular than that of the present day.

Dr. Ekholm, however, while applying the carbon-dioxide theory to the climatal variations of the Glacial Period, believes that those of post-Glacial times (some instances of which he mentions) were due to secular changes in the obliquity of the ecliptic. He calculates that at the periods when, owing to this cause, the summers of the Northern Hemisphere were warmer, one series of which occurred about 9100 years ago, the amount of heat received directly from the sun at the North Pole during the months of May, June, and July, was from 4·1° to 4·4° Cent. (=7·4° to 7·9° Fahr.) greater than at present, while about 28,300 years ago, when the summers were colder, it was from 6·3° to 7·1° Cent. (=11·3° to 13·1° Fahr.) less; the difference in each case during the winter months, when the sun is there below the horizon, being of course zero. He further believes that it was during one of these warmer periods, occurring about 48,000 years ago, that the final melting of the great ice-sheets took place.[1]

The great centres of ice-accumulation do not seem to have been at the North Pole, however, but very much farther south: one of the most important of them, that of Labrador, being situated in about lat. 55° N., while the edge of the American ice-sheet, at the time of its maximum extension, is believed to have travelled 17 degrees farther southward. Generally the phenomena with which the glacialist has to deal did not take place in the extreme north. The excess of heat received from the sun in summer at lat. 55° N., during the warmer periods, was not nearly so great as at the Pole itself, and the winters having been colder, no material annual increase of temperature could then have taken place.[2]

Both at the time when the obliquity was greatest and when it was least, the total difference in the amount of heat received from the sun in Labrador during the year was inappreciable, 0·54° Fahr. in the one case, and −0·54° in the other. When we remember that the summer-temperature of that region may be raised more than 30° Fahr., and its winter-temperature as much as 60° in the course of a few days, by a change of wind (see pp. 438 & 448), it will be seen how much more influence a permanent alteration in the prevalent character of the atmospheric circulation might have exerted on the melting of the American ice-sheet than the astronomical cause now suggested.

[1] It seems to me improbable that the close of the Glacial Period took place at so remote a date.

[2] Dr. Ekholm's figures showing the increase or diminution of heat received from the sun at lat. 55° N., as compared with that of the present era, are as follows:—

	9100 years ago. Cent.	Fahr.		28,300 years ago. Cent.	Fahr.
May	+1·7°	= +3·06°	....	−2·4°	= −4·32°
June	+1·9°	= +3·42°	....	−3·0°	= −5·40°
July	+1·7°	= +3·06°	....	−2·8°	= −5·04°
Summer months: Apl. to Sept.	+1·3°	= +2·34°	....	−2·0°	= −3·60°
Winter months: Oct. to March.	−1·0°	= −1·80°	....	+1·7°	= +3·06°

Dr. Ekholm's figures take no account, as he himself suggests, of the fact, that a part of the excess of heat received from the sun at the Pole would have been expended in the melting of snow and ice, and the evaporation of water. The cloudiness so produced, as at present in northern latitudes, must have tended to lower the temperature. The influence of the winds, moreover, would have dispersed any excess of heat which may have there arisen. So long as an ice-sheet continued in Labrador, the winds would probably have blown prevalently from that country towards the Pole, and possibly thence, on the view taken by me (figs. 18 & 20, pp. 452 & 456), in the direction of Europe, and not from the Pole to Labrador.

Evidence of a change of climate during the post-Glacial Period, similar to those mentioned by Dr. Ekholm, has been described by Mr. Clement Reid, F.R.S.,[1] who in 1896 found, in a lacustrine deposit at Hoxne (Suffolk), a bed containing leaves of Arctic plants, including three species of dwarf willow (*Salix myrsinites*, *S. herbacea*, and *S. polaris*) and the Arctic birch (*Betula nana*). In a bed conformable to, and immediately underlying this, the character of the flora suddenly changes, no specimens being found in it except those of plants and trees now growing in the East of England. It seems to me improbable that these closely related strata can represent any such extended period as those referred to by Dr. Ekholm, and if so, the climatic changes that they indicate may have been due to meteorological rather than to astronomical causes.

Dr. Ekholm gives many interesting particulars to shew that, during a period extending from the third to the end of the eighteenth century, the winters were occasionally more severe than they are now, in Scandinavia and North-western Europe on the one hand, and in Italy, the Adriatic, the Bosphorus, and Asia Minor on the other; but in no single case do the dates given for the abnormal seasons of the different regions coincide. He states, moreover, that Greenland and Iceland are believed to have formerly enjoyed a somewhat milder climate than that of the present day (*op. cit.* p. 49). Extreme winter-temperatures have not been unknown in the British Isles during recent years: a minimum of −16° Fahr. was recorded at Kelso in December 1879,[2] and winter maxima of 60° Fahr. and upwards are not uncommon. At present, conditions of excessive cold do not last long in these islands, as the prevalent position of the winter-anticyclones is not favourable to such a state of things. The anticyclonic systems shift, however, not only from day to day, and from season to season, but possibly also from age to age.[3] Why this is so we have yet to learn, but it is not difficult to understand that a comparatively slight alteration in the prevalent alignment of the winter-isobars and in the direction of the winds so resulting, might

[1] Rep. Brit. Assoc. 1896 (Liverpool) p. 400.

[2] Quart. Journ. Roy. Met. Soc. vol. xxvii (1901) p. 62.

[3] Among other facts cited by Dr. Ekholm are some to show that 300 years ago easterly and south-easterly winds were prevalent in Denmark, rather than those from the west and south-west as at present, *op. cit.* p. 52.

have caused, in former times, seasons milder in Greenland, and more severe in one part or another of Europe.[1]

While cordially acknowledging the great interest and value of the theories of Prof. Chamberlin and Dr. Ekholm, especially as applied to the more important changes of climate during past epochs, I am still inclined to think that the minor variations of the Pleistocene, the prehistoric, and the historic periods may have belonged to one great series of events, and have been alike due to the cause which gives Great Britain its variable seasons at the present day, namely, to alterations in the direction of the prevalent winds.

Discussion.

Sir Henry Howorth commented on the difficulty of discussing a meteorological paper at the Geological Society. He found himself unable to agree either with the Author's premisses or his conclusions. The Author, for instance, took the ice-sheet for granted. It was by no means clear whether he attributed his Pleistocene winds to the ice-sheet or his ice-sheet to the Pleistocene winds. He wished to know how the Author proposed to increase the evaporation of the temperate regions so as to secure a sufficient snowfall for his ice-sheet, and having got his requisite moisture, how was he going to increase the cold of summer sufficiently to prevent the winter's snow from being melted every year? The speaker believed that at present a fortnight or three weeks was sufficient to denude all snow-covered surfaces of their winter snowfall, except mountain-tops and some parts of the Arctic lands. The theory that the periods of glaciation of North America and Europe alternated was contrary to the generally expressed opinions of glacialists. The arguments founded on the Sahara and North-eastern Asia seemed equally at fault; and the more he tested the paper, the less he could find in it to agree with.

Prof. Sollas remarked that, if the conclusions to which the Author had been led might for the present be regarded as matters of controversy, there could at all events be no doubt as to the value of his methods. The Author had the honour of being the first to treat questions of ancient climate by the exact charting of Dr. Buchan, and this was likely to give greater definiteness to our discussions. One of the most important deductions to which the Author had been led, was that glacial conditions had alternated in the two hemispheres. It was to be hoped that it might be found possible to test this result by observation; but the extensive glaciation which had been found on high land within a few degrees both north and south of the Equator, and as well in the Old World as in the New, seemed to suggest some very general cause for the conditions of the Glacial Period; and if so, this might have operated in other ways than those considered by the Author. At present Greenland and Norway,

[1] See also T. C. Chamberlin, Journ. Geol. Chicago, vol. vii (1899) p. 770.

although under the influence of the North Atlantic depression, were both glaciated; and a general lowering of the mean temperature might have led to an extension of glaciation from these centres simultaneously. There were other factors besides distribution of temperature to be considered, in tracing out the atmospheric circulation, and meteorology was scarcely at present sufficiently advanced to enable us to make certain deductions from its principles.

Mr. A. E. Salter remarked that the theory advanced by the Author required the existence during the 'period of maximum glaciation in Europe' of a similar anticyclonic area in Central Asia. The diagrams and slides exhibited showed this very clearly. In the paper, however, on 'Recent Geological Changes in Northern & Central Asia' by Prof. G. F. Wright (in the recently issued number of the Quarterly Journal), it was stated, as a remarkable fact, that in spite of careful research no signs of former extensive glaciation could be detected in those regions.

Mr. P. F. Kendall said that he thought the Author had wisely made no attempt to explain the ultimate cause of the Glacial Period. He agreed with Prof. Sollas that that belonged to some extra-telluric agency, and was not the result of any modification in the attitude of the earth in relation to the sun. Mr. Culverwell had, he thought, shown very clearly that the eccentricity of the earth's orbit in conjunction with precessional movements was quite inadequate to produce a Glacial Period. Moreover the very recent date and the long duration of the Ice Age were decisively against Croll's hypothesis. At one time Interglacial periods were postulated upon very insufficient grounds, but he had been convinced by recent discoveries on both sides of the Atlantic that there had been mild intervals in the Glacial Period. The Author's interesting and valuable speculations offered a reasonable explanation of them, without invoking the precession of the equinoxes. The speaker could not share Prof. Sollas's optimism regarding the possibility of correlating the European and American Glacial and Interglacial deposits.

Mr. J. Lomas said that, although many workers in the past had attacked the problems brought before the Society that evening, none had been armed with the weapons which modern meteorological research had placed in the Author's hand. If it were acknowledged that glacial conditions ever existed over North America and North-western Europe, it followed that anticyclonic systems must have lain over the same areas, and these must have been fringed by complementary cyclonic systems. It seemed to him that the Author had worked on perfectly sound lines in reconstructing the areas of high and low pressure in the Pleistocene Epoch. It was quite obvious, too, that if the two hemispheres were anticyclonic at the same time, a condition of affairs would be set up which would be unstable; and it appeared almost essential that the fact should be recognized on meteorological grounds, that the Old and New Worlds were glaciated alternately. If these two important principles could be established, smaller points of detail might be left to adjust themselves. He did

not think it necessary to invoke epeirogenic changes to shift the centres of anticyclones. Such a system as that supposed to exist in the Western Hemisphere in Glacial times might move eastward by accretion on the east side, and an eating-away of the western side by the Northern Pacific cyclone.

The PRESIDENT and Sir JOHN EVANS also spoke.

The AUTHOR, in consequence of the lateness of the hour, replied very briefly to the various objections raised in the course of the discussion, expressing the hope that if the paper were published a number of these would prove to have been anticipated.

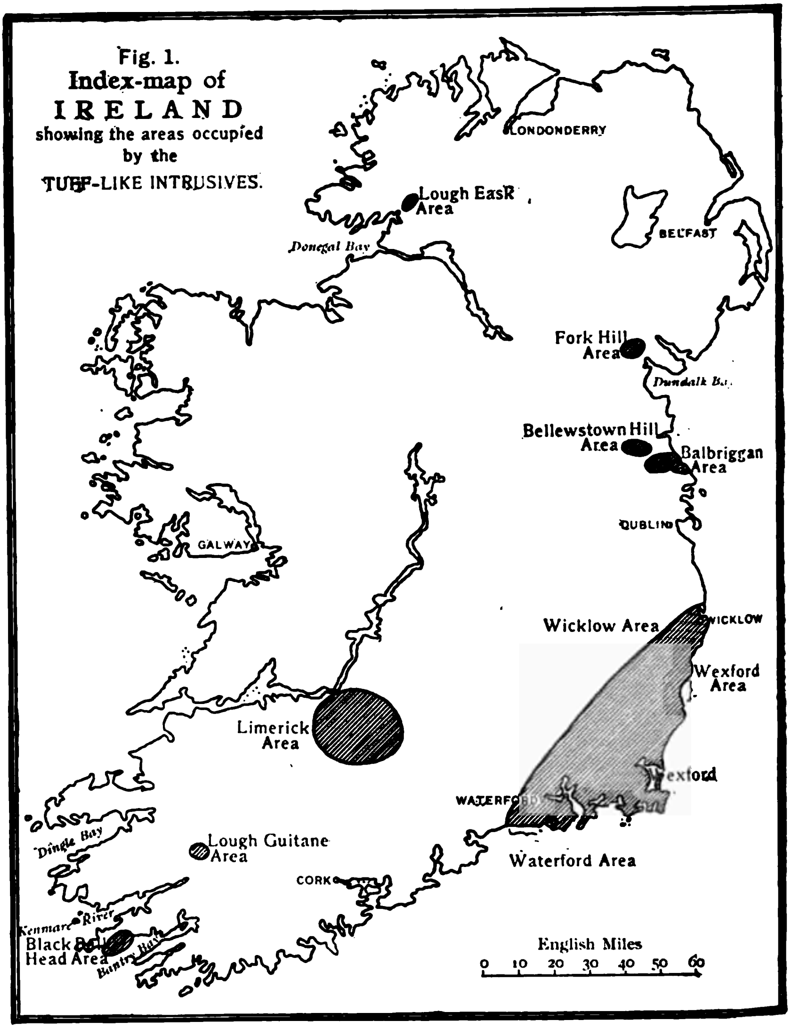
29. *On* Intrusive, Tuff-like, Igneous Rocks *and* Breccias *in* Ireland. By James Robinson Kilroe, Esq., and Alexander McHenry, Esq., M.R.I.A.[1] (Communicated by R. S. Herries, Esq., M.A., Sec.G.S. Read June 19th, 1901.)

For several years past it has been known to us that fragmental igneous rocks exist in different parts of Ireland, which, though they resemble tuffs, and in certain cases have been described as volcanic rocks, cannot be regarded as ejectamenta, on account of their character and mode of occurrence in the field. Of those which have come more especially under our notice, we may at the outset briefly mention a few particulars, to introduce our subject, before describing in detail the sections exposed in the South-east of Ireland which afford the chief evidence upon which our views of such rocks are based.

In the Explanatory Memoir (1888) accompanying Sheet 24 of the Geological Survey Map of Ireland, pp. 34 & 35, certain breccias occurring to the east of Lough Easke, in Donegal, are described as 'agglomerates,' though not in the sense of their having been at any time considered volcanic rocks. In parts, these masses might better be described as crush-breccias, as they, in such cases, follow lines of dislocation. In parts, however, they consist of partly-fused, broken-up, felspathic mica-schist or 'gneiss,' and they merge with felsite-dykes. Sometimes they occur dispersedly in sporadic masses in the mica-schist; and north-east of Lough Easke the breccia forms a wide band adjoining the granite, suggesting the conclusion that its formation may be attributed to the earth-stresses which immediately preceded, or in a sense accompanied, the intrusion of the Barnesmore granitic mass.

Rocks similar to these occur in the district of Forkhill, in Armagh, and are described as 'volcanic agglomerates' in the Explanatory Memoir (1877) accompanying Sheet 70 of the Geological Survey Map of Ireland, pp. 13, 14, 30, etc. In parts they consist of brecciated slate or brecciated granite and felsite, the fragments being embedded in a scanty andesitic matrix. The matrix increases in proportionate quantity downward, and passes by insensible gradation into the adjoining felsite, so that no hard-and-fast line of separation can be drawn between this rock and the so-called 'volcanic agglomerate.' Even where the mass is highly fragmental, the matrix is obviously crystalline, and therefore xenolithic andesite is the term which might more appropriately be applied to the breccia. This fact, considered in conjunction with the gradual passage above mentioned, points to the inference that, as all the fragmental so-called volcanic rocks of the region are of the same character, it is doubtful whether clastic rocks of volcanic origin exist there. It is

[1] Communicated by permission of the Director of H.M. Geological Survey.



[Figs. 2, 3, 4, & 7 illustrate the occurrences in the Wexford area, and figs. 5, 6, & 8 those in the Waterford area.]

a case of *petitio principii* to assume, even if the masses occupy the throats of ancient volcanoes, that the contained fragments were ejected during eruption.

Rocks of a similar character, apparently volcanic, though in reality hypogenic, occur at Balbriggan and Bellewstown Hill, north of Dublin, intrusive into Upper as well as Lower Silurian strata.

Rocks at Blackball Head, in Kerry, have been ascribed by Jukes and others to a volcanic origin, because of their fragmental nature [1]; but these rocks cross the bedding of the associated sedimentary strata of the region, are therefore intrusive and not contemporaneous, and may be of much later date than that usually assigned to them. Similar remarks apply to the nature and origin of some of the supposed 'ashes' of the Lough Guitane district, near Killarney, and some of those occurring in the Limerick area. We do not intend now to refer particularly to these, but pass on to the igneous rocks of the South-east of Ireland, pausing only to mention the work of other inquirers in this line of study.

It is with much gratification and encouragement that we have observed the remarks of Prof. Lapworth in this Journal, vol. lvi (1900) p. 23, when commenting upon Mr. Lamplugh's paper on 'Some Effects of Earth-movement on the Carboniferous Volcanic Rocks of the Isle of Man.' Considering the phenomena accompanying great movements of the crust, Prof. Lapworth conceives it possible that

'igneous matter making its way between the moving masses may consolidate as sills where the pressure is great. . . . As movement progressed intermittently we should have the formation of subterranean agglomerates, tuffs, and breccias, which would be forced locally sometimes between bedding-planes, sometimes into dyke-like fissures.'

The manner in which Mrs. Ogilvie Gordon accounts for the 'agglomerates' of the Gröden Pass and the Buchenstein Valley approaches somewhat closely the origin to which we attribute such masses. That authoress terms them 'shear-and-contact breccias' associated with felsite-veins, as distinguished from Prof. Bonney's 'crush-breccias.' [2] If it had been further allowed that the insertion of igneous rocks from below, accompanied by partial fusion of fragments detached from the broken-up masses, played a large part in the phenomena of the region, Mrs. Gordon's view of the origin of the agglomerates would nearly harmonize with that which we adopt to explain those that we have met with. We believe that in the South-east of Ireland are to be found abundant illustrations of the hypothesis suggested by Prof. Lapworth, namely, the subterranean formation of tuff-like masses. Their intrusion, however, does not always seem to have been accompanied by folding-movement of the adjacent sedimentary rocks, even if such were sometimes the case.

[1] See pp. 91, 92 of McHenry & Watts's 'Guide to the Collection of Rocks & Fossils Geol. Surv. Irel.' 1895.

[2] Quart. Journ. Geol. Soc. vol. lv (1899) pp. 567–69, 584, etc.

The accompanying map and sections (figs. 1–8) illustrate how tuff-like rocks invade black slate of Llandeilo age, generally adhering to the direction of bedding, but frequently cutting across it, and detaching from the slate numerous pieces. These are more numerous near the margins of the intrusion than at a distance, and retain so distinct a parallelism to the margins that we can only infer that in some instances there has been no great movement of the bounding walls.

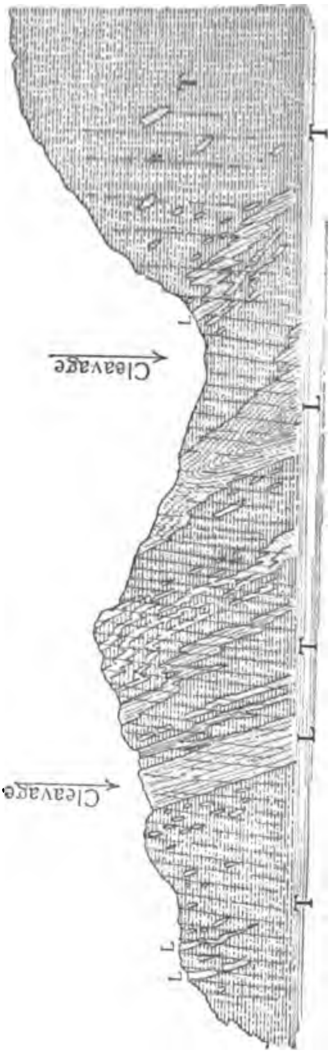


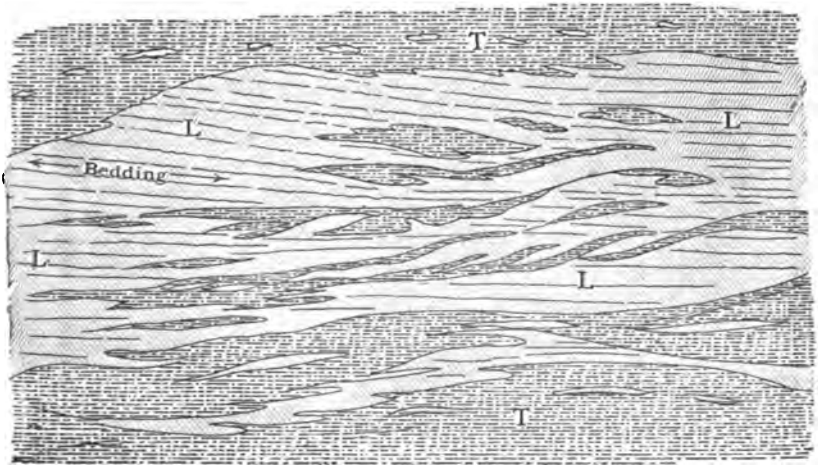
Fig. 2.—*Cliff-section immediately under Ballymoney Coastguard Station, 3½ miles east of Gorey (County Wexford).*

[Length of section = about 30 feet.]

L = Lower Silurian (Llandeilo) shales and fine grits, showing the contortions of the strata.
T = Fragmental rocks ('tuff'), with inclusions of black slate, grit, limestone, felsite, etc.

Sometimes the tuff-like rock contains large, irregular masses, mostly lenticular, as in figs. 2 & 3. Some of these masses are themselves invaded and almost severed across by veins of tuff-like material projected from the enclosing magma. The section shown in fig. 5 (p. 484) is the bottom of a cliff-face about 60 feet in height; the base is so exceedingly ash-like that specimens were collected as exhibiting the fragmental character of an 'ash.' Above the base the section is involved and not easily interpreted, and higher up are large included masses of black slate disposed generally parallel to the base, which, on the hypothesis of the mass being intrusive, represent the remnants of sedimentary pre-existing strata,

Fig. 3.—*Section on the coast, a short distance north of Duffcarrick, 3½ miles east of Gorey (County Wexford).*



[Length of section = 3 feet.]

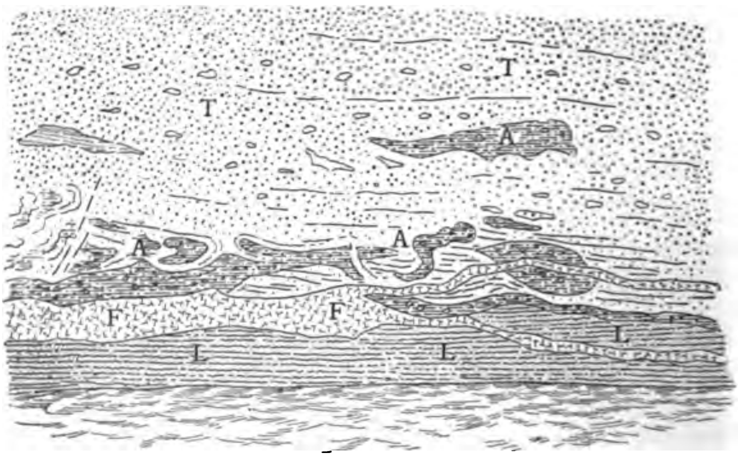
Fig. 4.—*Section on the coast, a short distance south of Ballymoney Coastguard Station, 3½ miles east of Gorey (County Wexford).*

[Length of section = 2 feet.]

B = Bala Limestone. L = Llandeilo black slate.
T = Fragmental intrusive rock ('tuff'), with inclusions of slate, grit, limestone, basic and acid igneous rocks, etc.

among which the tuff-like rock was intruded in the form of a succession of thick sills. So distinctly is the mass as a whole not a rock of purely clastic, subaërial, or submarine origin that it contains masses of tuff-like rock as shown at A in the section; and following the direction of apparent dip westward along the cliff, the same mass is to be observed some 50 yards off, penetrating a remnant of the black slate of more important dimensions than any of the included pieces, and, as is believed, occupying its natural position in the stratigraphy of the sedimentary rocks. Passing the point at which this exposure of black slate is seen, the succession of massive layers of apparent 'tuff' continues westward for a considerable distance.

Fig. 5.—*Cliff-section at St. Ronan's Bay, south of Tramore (County Waterford).*



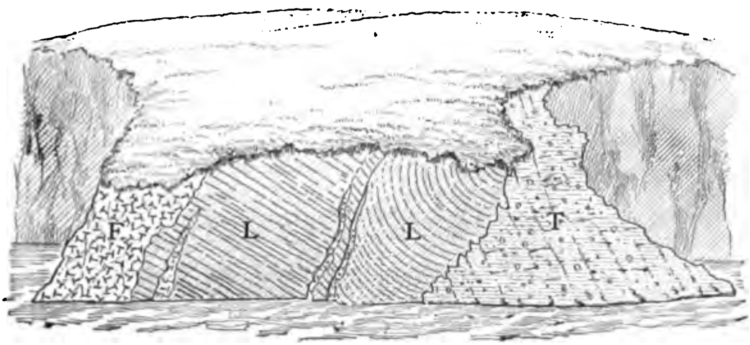
[Length of section = 30 yards.]

L = Llandeilo black slate.
T = Fine fragmental rock ('tuff')
F = Later felsite.
A = Coarse fragmental rock ('tuff'), with inclusions of slate, etc., and flow-structure at the base.

The rocks of this coast have lately been described by Mr. F. R. Cowper Reed,[1] who regards some of the fragmental masses as xenolithic felsites, and some as 'agglomerates.' The author refers to coarse igneous breccias at Annestown as xenolithic felsites (*op. cit.* p. 665). These were represented as volcanic ash on the Geological Survey Maps, and might be taken for such. They form, however, a succession of great sills such as that above described, and near Carrickadurrish rock, truncate a series of calcareous slate-beds, as may be well seen in the cliff, and is shown in fig. 6. This

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) pp. 657–92.

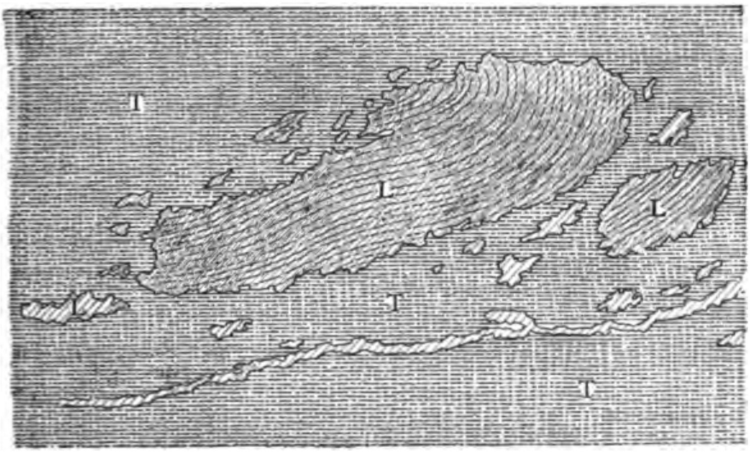
Fig. 6.—*Cliff-section at Annestown, south-west of Tramore (County Waterford).*



[Length of section = 50 yards.]

L = Llandeilo black slate and calcareous grit.
T = Fragmental rock ('tuff'), with inclusions of black slate and felsite.
F = Felsite.

Fig. 7.—*Section on the coast near Ballymoney Fishery, $3\frac{1}{2}$ miles east of Gorey (County Wexford).*



[Length of section = 6 feet.]

L = Llandeilo black slate, showing contorted bedding in the inclusions.
T = Fragmental intrusive rock ('tuff'), sometimes rudely arranged in the mass to resemble bedding = ? flow-structure.

mass, continued eastward across Annestown Bay, sends veins and sills into the sedimentary strata forming Green Island, and may be seen at low water surrounding a mass of black slate between the island and the mainland. A little farther east the coarse fragmental rock, described as xenolithic felsite by Mr. Cowper Reed, contains and gradually merges into distinctly stratified rock which closely resembles tuff. The origin of the whole mass is perplexing, for near to the spot where stratification is so distinctly seen a vein of black slate, only an inch or two in thickness, is traceable for a long distance in the face of the cliff. This we believe to be a remnant of the sedimentary rock which the tuff-like mass invaded, and not at all a deposit contemporaneous with the mass. The direction of this vein, moreover, is not parallel to the structure of the stratified portion above mentioned, but is more nearly at right angles to the strike of the apparent stratification. A similar thin vein of black slate is to be observed near Ballymoney Fishery, in Wexford, as shown in fig. 7 (p. 485).

At Arklow Rock and Duffcarrick, on the coast in the counties of Wicklow and Wexford, the intrusive nature of those massive, apparently bedded, tuff-like rocks is most impressively exhibited. This structure is well exhibited on the coast, $1\frac{1}{2}$ miles south of the town of Arklow, where tongues from the tuff-like rock penetrate black slate of Llandeilo age. A similar disposition of these igneous rocks is to be seen in the neighbourhood of Ballymoney Coastguard Station, and that they cannot be regarded as in any sense contemporaneous with the slate is proved by their containing pieces of limestone of Bala age as well as pieces of the black slate (Llandeilo).

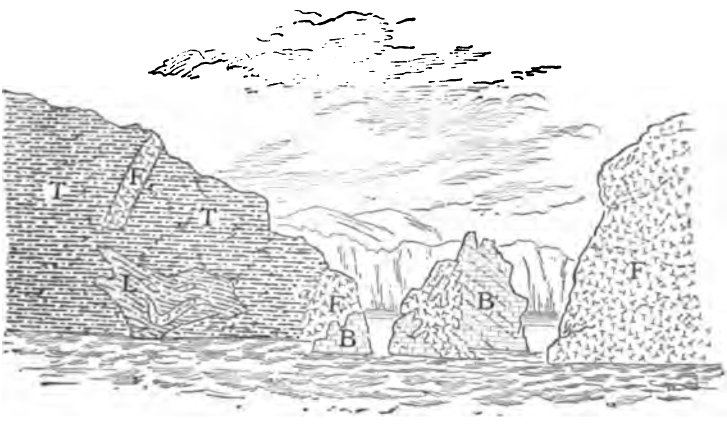
Portions of the Arklow intrusive rock were examined microscopically, both by Mr. Teall and Mr. Seymour, and were found to yield the usual indications of rocks hitherto regarded as unquestionable tuffs.

Farther south, fine-grained felsitic rocks, arranged in layers, occur at Duffcarrick on the Wexford coast. These rocks, because of their stratified appearance, and because under the microscope they present a thoroughly clastic appearance, have been regarded as still more unquestionably tufaceous in origin. They nevertheless invade the adjoining sedimentary rocks, a peculiar banded slate—the prevailing rock of the country, known as 'ribbon-slate.' The sections and plans selected for publication by no means exhaust the evidence bearing upon the important question at issue obtainable in the localities referred to; they are submitted to the Society as a selection, to illustrate the nature of the evidence for the intrusive character of these tuff-like igneous masses.

The sections at Sheep Island, on the Waterford coast, 2 miles west of the entrance to Tramore Bay, are equally instructive, as showing that microscopic rock-structure cannot be relied upon, apart from field-evidence, to afford the ground of decision regarding the

origin of fragmental igneous masses. Fig. 8 shows a view of the mainland and the northern end of Sheep Island. Here are seen the light buff-coloured and green felsites, which in parts present a tuff-like aspect, and are described by Mr. Cowper Reed as tuffs.[1] The green rock has invaded the light-grey felsite and limestone, which it has in parts marmorized and in parts thoroughly impregnated with green (? chloritic) matter, as appears in the small islet in the figure. Though the green felsitic rock sends veins into the adjoining felsite, as seen in the accompanying figure and at the east side of the spur on the mainland near the islet (as shown in Sir Archibald Geikie's sketch),[2] the line of demarcation between the two felsites on the western side of the spur is not so obvious; there seems, in fact, to be a gradation (though across a line of fracture)

Fig. 8.—*View of Sheep Island promontory, south-west of Tramore (County Waterford).*



[Length of section = 50 yards.]

L = Llandeilo black slate. T = Pinkish-grey felsite, } both in parts
B = Bala limestone. F = Dark green felsite, } tuff-like.

from the green fragmental mass into broken-up, light-grey felsite, which contains a vanishing amount of green matter from the later rock as a cementing-matrix. Specimens from these two fragmental varieties have been microscopically examined and found to contain hourglass lapilli, indicative of tufaceous structure.

Mr. H. J. Seymour has ingeniously suggested[3] a method of accounting for such lapilli in intrusive rocks, namely, that they represent the glassy interspaces between spherules in rapidly-cooled masses which were mechanically fractured by pressure after cooling.

[1] Quart. Journ. Geol. Soc. vol. lvi (1900) p. 663.
[2] 'Summary of Progress of Geol. Surv. U. K.' for 1899, p. 80.
[3] *Ibid.* pp. 179, 180.

We suggested, and in this Mr. Seymour agrees with us, that the fracturing occurred in connection with continued intrusion after portions of the invading magma had solidified in smaller veins. The occurrence of lapilli of pumice in these intrusive rocks we conceive may be accounted for in a somewhat similar manner, namely, the sudden opening out of fissures and subterranean chasms before the invading masses, which would admit of the development of a vesicular structure in the rapidly-cooling magma, and the subsequent fracturing and mincing-up of the newly-formed rock.

The cleavage of these masses and of the felsites in certain places —subsequently to the folding of the strata which occurred prior to the invasion by the igneous masses—has led to the mistaken conception of the true origin of the intrusive rocks. Planes of cleavage which sometimes accord with the bedding-planes, though most frequently crossing the bedding, induced Jukes and Du Noyer, who examined the ground, to suppose that even the cleaved felsites were volcanic ashes. Sir Archibald Geikie and Dr. Hatch, on visiting the ground some years ago, perceived that this was a superimposed structure.[1] Mr. Kinahan seems to have observed the true disposition of the fragmental tuff-like rocks, as he mentions instances of their intrusive character in the Explanatory Memoir (1882) accompanying Sheets 158 & 159 of the Geological Survey Map of Ireland, p. 16, but did not follow up the inquiry. The importance of the subject in igneous geology will be readily admitted. That there are contemporaneous igneous rocks in the South of Ireland we are well aware, though the evidence for their local occurrence may need reinvestigation on the lines above indicated. Igneous action began in the district after the limestone of Bala age was formed, and was continued with intermissions up to the epoch at which Upper Old Red began to be formed, chiefly during Old Red Sandstone times, the period probably in which the Leinster granite and the associated felsites were intruded. To this period we venture to assign most of the tuff-like rocks.

Indeed, we are strongly inclined to believe that these intrusive breccias in most cases represent the marginal phenomena of the granitic eruption, since we find outlying intrusions of the granite passing into the felsitic laccolites which aré directly associated with the intrusive fragmental rocks. This passage is to be seen at many points in the South-east of Ireland. It is most apparent to the south of Vinegar Hill, near Enniscorthy (Sheet 158), where the fragmental felsite graduates into an elvan, and from that into a granite; also farther south-west, about 10 miles from Enniscorthy; and again still farther south-west, in the laccolite-hill of Carrickburn (Sheet 169), where the granitic central core passes outward into a felsitic rock showing flow- and spherulitic structures, and which is, moreover, very considerably brecciated and fragmental on its outer margin, the rock-mass under these latter conditions being hitherto always regarded as 'tuff.' The passage from granite into felsite is also well shown near Mount Druid, in County Waterford.

[1] 'Summary of Progress of Geol. Surv. U. K.' for 1898, p. 59.

The present disposition, character, and behaviour of these rocks, and of their associated felsites, some of which are semivitreous and exhibit flow-structure, seem to us best to be explained by conceiving them to have been intruded among the strata as sills or successions of sills, and in certain cases as rudely-outlined laccolites.

It is certain that, whatever the origin of the masses we describe, their true character and disposition have been overlooked in Ireland. Judging from what we know of so-called 'contemporaneous igneous rocks' in the Lough Guitane district near Killarney, and their disposition in the field, as well as of some of those in the Limerick basin, we believe that more rigid examination of these areas would reveal the existence of masses younger—possibly much younger—than the surrounding sedimentary strata. The igneous rocks of Wales have long been recognized to be the counterparts of those in County Wexford, and it may ultimately be found that among the great series of supposed volcanic rocks occurring in Wales are some tuff-like masses of even later date than the Silurian Epoch, as in Ireland.

Discussion.

The President, Mr. Marr, Prof. Groom, and Prof. Watts spoke.

The present disposition, character, and behaviour of these rocks, and of their associated felsites, some of which are semivitreous and exhibit flow-structure, seem to us best to be explained by conceiving them to have been intruded among the strata as sills or successions of sills, and in certain cases as rudely-outlined laccolites.

It is certain that, whatever the origin of the masses which we describe, their true character and disposition have been overlooked in Ireland. Judging from what we know of so-called 'contemporaneous igneous rocks' in the Lough Guitane district near Killarney, and their disposition in the field, as well as of some of those in the Limerick basin, we believe that more rigid examination of these areas would reveal the existence of masses younger—possibly much younger—than the surrounding sedimentary strata. The igneous rocks of Wales have long been recognized to be the counterparts of those in County Wexford, and it may ultimately be found that among the great series of supposed volcanic rocks occurring in Wales are some tuff-like masses of even later date than the Silurian Period, as in Ireland.[1]

Discussion.

The President, Mr. Marr, Prof. Groom, and Prof. Watts spoke.

[1] [Mr. H. J. Seymour requests us to state that we have not quoted him correctly in the foregoing pages. For the correct reading of his views, see 'Summary of Progress of Geol. Surv. of U.K. for 1899' pp. 179 & 180.—*J. R. K. & A. McH., October 22nd, 1901.*]

30. *On the* Geological *and* Physical Development *of* Antigua.

By Prof. Joseph William Winthrop Spencer, M.A., Ph.D., F.G.S. (Read April 24th, 1901.)

[Plate XV—Map.]

Contents.

I. Introduction and Early Observations.

The island of Antigua may be taken as a starting-point for the study of the Windward Islands, as within its area of 100 square miles almost all of the geological and geographical features of the region, except the later volcanic phenomena, are developed in such a way as to be easily understood. The only other island comparable for a base of study is Guadeloupe, which furthermore includes all the recent volcanic features on a grand scale, but some other features less easily distinguishable than in Antigua.

On November 5th, 1819, Dr. Nicholas Nugent, a physician of Antigua, communicated to the Geological Society of London 'A Sketch of the Geology of the Island of Antigua'[1]; but a 'Memorandum' of this had been sent to Benjamin Silliman on April 10th, 1818, and was published two years earlier in America[2] than the fuller London paper. Nugent also sent to the Geological Society large collections of the rocks and fossils, carefully labelled as to their horizons. These remained almost unstudied for over forty years, when P. Martin Duncan made an elaborate study of the corals contained in them,[3] which appeared in 1863–64.

Nugent had a companion in his studies of the island in the

[1] Trans. Geol. Soc. ser. 1, vol. v (1821) pp. 459–75.

[2] Am. Journ. Sci. ser. 1, vol. i (1819) pp. 140–42. The petrified wood of Antigua had even before this attracted attention; and a notice of a collection made by Pelatiah Perit (of New York) is found a little earlier than Nugent's 'Memorandum,' on p. 56 of the same volume of the Am. Journ. Sci.

[3] 'On the Fossil Corals of the West Indian Is.' Quart. Journ. Geol. Soc. vol. xix (1863) pp. 406–58, & vol. xx (1864) pp. 20–44, 358–74.

person of Dr. Thomas Nicholson, who wrote a short account of the geology of the island in the 'Antigua Almanac & Register,'[1] a work forgotten or lost. Prof. S. Hovey[2] visited the island, with Nugent as his guide, and published a sketch of the 'Geology of Antigua' in 1839 (as he says) on account of the inaccessibility of Nugent's paper in America. In this publication there was little marked advance. Nugent had described the igneous belt of the western portion of the island; the 'clay' and 'conglomerate'-zone in the centre, with the chert-deposits containing silicified wood, freshwater shells, etc.; and the fossiliferous white marl and limestones occupying the eastern or larger belt; as also the recent coral-fringes. Even in 1818, Nugent had recognized the Tertiary character of the marls, and said (Am. Journ. Sci. vol. i, p. 142) that in the West India Islands there was

> 'proof of an extensive formation, more recent than those to which naturalists have heretofore principally confined their attention.'

Nugent's paper showed a remarkable degree of perspicuity, and remained the only classic on the geology of the island for over sixty years, until the appearance of the studies of M. J. C. Purves, published at Brussels in 1885.[3]

At the time of my visit, I had not seen the work of M. Purves (Curator of the Royal Natural History Museum in Brussels), which will be referred to in succeeding pages, and I am not aware that any geologist had visited the island for the purposes of investigation subsequent to M. Purves, until my own visit in 1896–97. But I met there, interested in the geology of their island, two gentlemen, whose assistance and kindness I wish to acknowledge, Mr. Frank Watt, the Island Chemist, and Mr. W. R. Forrest. The Rev. Mr. Branch is also keenly interested in the natural history of the island.

None of the previous writers had made a study of the two formations more recent than the marls, or of the evolution of the physical features since the Oligocene Period (age of the limestones); all of which phenomena were the special objects of my visit, for the purpose of correlating them with the later life-history of the Greater Antilles and the adjacent continent, especially the evidence of great changes of level of land and sea. My theoretical expectations were realized.

II. Situation and Physical Characteristics.

Antigua and Barbuda rise from the same bank, which occupies the north-eastern portion of the chain of the Lesser Antilles.[4]

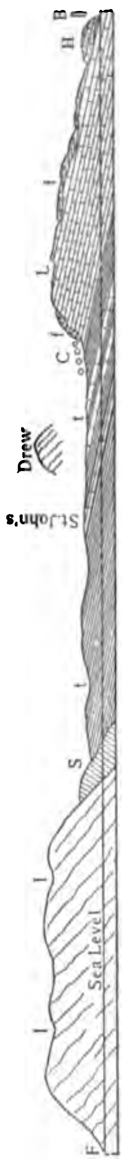
[1] A copy was seen by Prof. Hovey in 1839.

[2] At one time Professor in Yale and Amherst Colleges. See Am. Journ. Sci. ser. 1, vol. xxxv (1839) pp. 75–85.

[3] 'Esquisse géologique de l'Ile d'Antigoa' Bull. Mus. Roy. Hist. Nat. Belg. vol. iii (1884–85) pp. 273–318.

[4] See U.S. Hydrographic Chart No. 40, or the corresponding British Admiralty Chart.

Section across Antigua from Five Island Point to Hodge's Hill; distance about 9 miles.



I I = Old igneous basement.
S = Seaforth Limestone.
t t = Tuff series, with layers of marine cherty limestones, and also fresh-water cherty beds.
L = White Limestone Series.
f f = Friar's Hill Marls.
H = Hodge's Hill Series, on an isolated prominence near B.
C = Cassada-Garden Gravels; Drew's Hill, a later volcanic prominence rises out of tuffs south of the line of section.
B = Another volcanic remnant rising through the White Limestones.

This bank is about 55 miles long and from 18 to 28 miles wide, with an area of 1400 miles. It is only slightly submerged, to a very uniform depth of about 100 feet. But even from the nearest islands — Guadeloupe, Montserrat, and Nevis, which are situated on the same great submarine plateau or ridge — this island bank is separated by somewhat broad depressions reaching to a depth of 1800 feet, or in a few places the narrower channels have depths from 2000 to 2500 feet. Thus the bank presents a striking physical unit, as of an extensive plain interrupted by low hills, with the remains of mountains occurring on the southern side of what is now the island of Antigua. The margins of the bank are everywhere abrupt and precipitous, and they are somewhat indented by deep valleys extending to the more profound depressions.

The island of Antigua has a maximum length (east and west) of 16 miles and a breadth of 13, with an area stated at 108 square miles. But the coast-line, especially of the eastern half, is very much broken up into lobes by shallow bays. These are occupied by numerous islands, keys, and reefs, among which the extension of the land-valleys can be followed.

The portion of the island south, or south-west, of a line extending from the hills 2 or 3 miles west of St. John's across the island to Falmouth Harbour, forms a zone characterized by the remains of old mountain-ranges (the highest summit, Boggy Peak, reaching to 1330 feet above the sea), and relatively large deep valleys. There are few precipitous cliffs, but the declivity of the mountain-sides is steep, and the streams in the deep valleys rapidly descend to the lower reaches, which are much broadened out, with flats so low that the deepening processes no longer obtain. The general erosion-features of this zone are those of a mountain-plateau, which has been dissected for

so long a time by atmospheric agencies that only narrow ridges remain between the valleys and ravines.

The central portion of the island, with the mountain-belt, as just described, on one side, and bounded on the other by a line of interrupted hills, extending from Dickenson's Bay (near Wetherell Point) to Willoughby Bay, on the southern coast, is characterized by plains at only a slight elevation above the sea, out of which rise isolated hills, among which Drew's has a height of 356 feet.

The remaining, north-eastern portion of the island forms a third zone, which is marked by undulating plains and hills rising to between 200 and 350 feet above the sea—in one case alone to 450 feet. In this portion of the island the drainage is largely absorbed into the porous strata, and is carried off below the surface, leaving it devoid of permanent streams.

The diverse features of these three belts are dependent upon their geological structure, and their boundaries mark the confines of the principal formations.

III. The Igneous Basement of the Island.

The foundation-rocks of the island appear at the surface, in the mountain-belt described above. Their general character, as then understood, was recognized by Nugent, and has recently been more fully described by M. Purves.[1] He shows that the rocks form a dolerite consisting of triclinic felspars, with little or no magnesian silicate. The phenocrysts are vitreous felspar; angular grains of magnetite are associated with them. This is an intermediate eruptive, and if included in Palæozoic rocks would be called a porphyrite, but if in Tertiary rocks an andesite. There is nothing in the character of this rock to establish its age. All that can be said is that it is pre-Tertiary, on account of its underlying the older Tertiary deposits. In places the rock is strongly porphyritic. Among the hard eruptives occur irregularly beds of fragmental materials or breccias and ashes, which have been more or less subjected to alteration, and these dip north-eastward, passing under the newer formations of the island. The compact trappean beds are often found decomposed, forming a residual soil many feet thick.

The eruptive formations suffered great denudation, both before the succeeding deposition of the Tertiary formations and since the close of the early Miocene Period. The long denudation, under varying conditions since that time, has largely given rise to the physical features of the island with which we are concerned. Such old igneous rocks occur in many of the Windward Islands, but in the ordinary accessible literature they are not generally distinguished from the much later volcanic eruptions which have broken through the older formation.

[1] Bull. Mus. Roy. Hist. Nat. Belg. vol. iii (1884–85) p. 279.

IV. The Seaforth Limestones.

At a few points in the valleys of the mountain-zone, as at Seaforth and the adjacent estate of York (which I visited along with Mr. Forrest), there is a very compact dark-grey limestone, in appearance resembling old formations, even of Palæozoic age. The beds dip at considerable angles south-westward. Only fragments of these deposits remain, in protected places, on account of subsequent denudation. This appears to be the oldest formation succeeding the igneous rocks, although this limestone has not been found eastward of the mountain-zone, beneath the stratified rocks which overlie the old trappean deposits. Nothing can be said as to its age, for no fossils were found in it, but it resembles limestones of other islands, and on this account, and because of its very different character from the Tertiary formations, it is possible that it may be as old as the remains of the Cretaceous Period, such as are seen in the island of St. Croix.

V. The Tuffs and included Marine and Freshwater Cherts.

Extending diagonally across the island, in a belt from 2½ to 4½ miles wide, and occupying the central plains and the north-western flank of the mountain-zone (up to an altitude of 695 feet in the case of the isolated hill called Monk's Hill), there is a very thick formation of stratified tuffs. These beds dip from 12° to 20° north-eastward.

The tuffs are made up of more or less decomposed angular and subangular fragments of trappean rocks, and contain minute crystals of felspar and magnetite. While the tuffs of fine texture predominate, near the mountains they become a conglomerate. In some cases the particles are waterworn. The colour is greenish to brown, and even whitish where kaolinization is more complete. These tuffs appear to have been derived from the denudation of the older volcanic formation, which extended to the nearest islands (30 miles distant). Drew's Hill,[1] situated in the middle of the zone, seems to have been produced by a renewal of volcanic activity, long after the commencement of the epoch of the tuffs, and may have contributed in a measure to the mass of that formation.

Lying conformably within the tufaceous group are lenticular masses of cherty limestone, containing rounded or fragmentary remains of shells and corals. These rocks give rise to isolated prominences. Higher come strata of sands and grits with water-worn volcanic fragments; and still higher are irregular thin layers

[1] The core of this hill is a compact crystalline eruptive, rising vertically through the tuffs to the summit, and is described by M. Purves as a trachy-dolerite, containing large crystals of triclinic felspar, with a pyroxenic mineral and grains of magnetite. It is the presence of the pyroxenic mineral which distinguishes this rock from the older igneous formation.

taining well-preserved fragments of silicified wood and
ls. In the lower marine limestones the shells were
ed for identification, but M. Purves obtained five
ggesting Miocene age; and some of the corals
rom the Nugent Collection showed that the
older Miocene. But Prof. Rupert Jones
Nugent Collection containing *Orbitoides*
make the formation from which it came
r Eocene of the American continent.
er cherts M. Purves found eight genera[4] of
n an excellent state of preservation. Five of
are not found in more recent beds in the island; and
of the other three genera cannot be identified with the
modern forms now living on the island. The evidence of the
, derived from these long-extinct forms, supports the antiquity
indicated by the corals.

Collections of fossils from the freshwater beds, which Mr. Forrest found intercalated in the tuffs, were kindly given to me by him.

Suffice it here to say that the tufaceous deposits, while older than the succeeding marls resting conformably upon them, had a fauna somewhat different from, though closely related to the latter. For other information concerning the beds of tuff and their enclosed cherts, M. Purves's work should be consulted.

[1] *Prionastræa diversiformis*, Mich. Upper Miocene, Bordeaux and Turin.
Solenastræa turonensis, Mich. Miocene, Turin and Touraine.
Stylocœnia lobato-rotundata (Mich.). Miocene, near Turin, etc.
Porites Collegnana, Mich., equivalent of *incrustans*, Ed. & H. Miocene, Turin.
Alveopora Dædalæa, Forskål. Recent, Red Sea, Indian and Pacific Oceans.

[2] *Astræa cellulosa*, var. *curvata*, sp. nov.; *A. megalaxona*, sp. nov.; *Solenastræa turonensis*, Mich.; *Isastræa conferta*, sp. nov.; *I. turbinata*, sp. nov.; *Stephanocœnia tenuis*, sp. nov.; *Cœloria dens-elephantis*, sp. nov.; *Astroria polygonalis*, sp. nov.; *A. affinis*, sp. nov.; *A. antiguensis*, sp. nov.; *Astrocœnia ornata*, Ed. & H.; *Alveopora Dædalæa*, Blainv., var. *regularis* & *minor*; and later he added *Stylocœnia lobato-rotundata* (Mich.), found also in the lower limestone of Malta.

Thus, three species are like European Miocene, nine peculiarly Antiguan species, and *Alveopora Dædalæa* is recent. Duncan added three species as coming from the tuff, namely, *Stephanocœnia tenuis*, *Astræa cellulosa*, and *Mæandrina*, sp., but M. Purves points out that these come from a horizon in the tuff above the chert-beds. See Duncan, Quart. Journ. Geol. Soc. vol. xix (1863) p. 411 & Geol. Mag. 1864, p. 97.

[3] Geol. Mag. 1864, p. 102. M. Purves thinks, however, that the specimen containing *Orbitoides* came from the higher limestone, which would suggest a somewhat earlier Tertiary date for all the deposits.

[4] Bull. Mus. Roy. Hist. Nat. Belg. vol. iii (1884–85) p. 294. The five genera confined to the island are *Melania*, *Zonites*, *Nematura* or *Amnicola*, *Neritina*, and *Pomatias*, and the three genera with species still living are *Planorbis*, *Melampus*, and *Truncatella*. M. Purves says that *Melania* proper does not live in the West Indies, but the subgenus *Hemisinus* occurs in Cuba. *Zonites* does not occur in the West Indies, though a species was found by M. Purves in Demerara. *Neritina* is scattered over the islands, but not in Antigua. *Nematura* is found in the East Indies and in the Oligocene of the Isle of Wight.

VI. The White Limestones or Antigua Formation.

The north-eastern portion of the island is underlain by a white limestone or marl, which is the 'Marl' formation of Nugent (or the 'Upper Limestones and Marls' of M. Purves). This formation is composed of an earthy marl and beds of compact limestone, often hard and durable enough for building purposes. White is the prevailing colour, but it is sometimes greyish or yellowish in the lower beds. The limestones are distinctly bedded, and dip from 12° to 20° north-eastward; but the bedding in the earthy or marly beds is often obscure. These varieties of rock pass one into the other. This formation is apparently conformable to the underlying tufaceous beds. The thickness of the limestone was not determined, but there still remain of it at least many hundred feet. The limestones are in part capped by a mechanical deposit, which has not been distinguished from the limestones by any previous observer. This series gives rise to the undulating hilly country occupying the north-eastern part of the island, the rolling features of which are the remains after the enormous degradation of the limestone at a comparatively slight altitude above the base-level of erosion. From the dip of the strata it naturally follows that the slopes towards the south-west are somewhat more abrupt than in the opposite direction.

The importance of this formation arises from two facts:—first, that it was the last great accumulation before a very long period of denudation, which removed not only a large proportion of the limestones themselves, but also exposed the older features; and secondly, on account of its containing a fauna by which the age of the beds can be determined. The question is not one of local distribution on the island, but rather one concerning the whole North-eastern Antilles, as showing that the phenomena described did occur in that region, during the geological periods ascertained. These limestones generally form the summits of the higher hills, but at the lower altitudes they have their very much eroded surfaces covered by a thin mantle of mechanical deposits, which have sometimes been removed in artificial cuts and otherwise.

At the north-western end of this belt, the sea has encroached upon the high lands, where at Wetherell Point it has formed a bluff about 100 feet high. Here both the hard and the marly beds occur, each being highly fossiliferous in places. Some of the harder beds appear to be made up of *Ostrea*. There are also other species of molluscs, but they are mostly in a poor state of preservation, and seldom consist of more than casts. The most important fossils found here are the smaller corals which predominate in the softer beds and are often silicified, thus preserving the structure so as to be determinable. I observed fossils at other localities, but nowhere so abundant as at Wetherell Point. The only corals that have hitherto been collected were those sent by Nugent to London in 1819, and studied by Duncan, who enumerates eleven

species (of three genera) and some additional varieties as here named [1] :—

> *Astræa crassolamellata*, sp. nov., with varieties *magnetica*, *pulchella*, *nobilis*, *minor*, *Nugenti*, and *magnifica*; *A. antiguensis*, sp. nov.; *A. endothecata*, sp. nov.; *A. tenuis*, sp. nov.; *A. barbadensis*, sp. nov.; *A. radiata*, Lamarck, var. *intermedia*; *A. costata*, sp. nov.; *Rhodaræa irregularis*, sp. nov.; *Alveopora Dædalæa*, Blainv., var. *regularis*; *A. microscopica*, sp. nov.; *A. fenestrata*, Dana.

I have seen no determination of the shells collected by Nugent, but with regard to some of them, Duncan says that they were unfortunately determined by some good authorities to be specifically identical with forms now existing in the reefs round the island. I might suggest that these recent types of shells may have come from the lower altitudes above the sea, and belonged to a different horizon not distinguished by the collector from the White Limestone Series, for, as already stated, the earlier observers confounded an overlying accumulation with the great formation now being studied.

My collection of corals has been kindly determined for me by Dr. T. Wayland Vaughan, who found the following species :—

Trochosmilia sp. nov.
Stylophora sp.
Stephanocœnia sp.
Astrocœnia ornata, Ed. & H.
Brachyphyllia sp.
Orbicella (*Astræa*) *crassolamellata*, Duncan.
Orbicella cellulosa, Duncan.
Orbicella endothecata, Duncan (=*cavernosa*, Linn.).
Orbicella sp.
Symphyllia sp. nov.
Astroria polygonalis, Duncan.
Oroseris sp. nov.
Alveopora regularis, Duncan.
Porites sp. nov. (?).

Besides these corals a species of *Orbitoides* was also found.

This list includes eight new or undetermined species of other genera, not found by Duncan, and six species common to the two collections. Two of these species are those which Duncan found in collections from the marl-beds; three from those belonging to the chert-beds (that is, midway within the great beds of tuff) or in the tuff itself; and one species common to the marl and the lower beds. Thus while Duncan recognized a difference in the fauna of the lower and upper beds, he found that they were closely allied, and the present collection still further emphasizes this point. Accordingly it would appear that the underlying beds of tuff with the overlying White Limestone form scarcely more than one geological unit, although characterized by great changes in the physical conditions during the accumulation of the system.

This collection of mine contained old types only. Duncan identified some of the species as belonging to the Miocene Period of the Old World. A few he found to be recent, but related to those of other West Indian islands, though the nearest analogies are found in the Indian and Pacific Oceans. The majority of the species are peculiar to Antigua, but none of them have any relationship with the living forms in the adjacent waters, showing a complete gap between them and the coral-fauna of the marls.

[1] Quart. Journ. Geol. Soc. vol. xix (1863) p. 410.

From these considerations Duncan inferred that the formation belonged to the mid-Tertiary or Miocene Period.

It has been stated before (p. 495) that Prof. Rupert Jones had found an *Orbitoides Mantelli* in the Nugent Collection. I also found a species of *Orbitoides* in the marls of Wetherell Point. This fossil is one of the most important collected, as it affords a correlation with the Tertiary of the South-eastern States, and would suggest that the formation is somewhat older than the mid-Tertiary Period, in a word, that the rocks are older Miocene or Oligocene. Thus it would appear that the time of this formation was a continuation of that of the fossiliferous beds of the tufaceous deposits (reaching probably to a thickness of several thousand feet)—the whole being one undivided geological unit, referable to the older Tertiary Period (including the Eocene and extending to the later Oligocene days).[1]

The shells of the same formation, which, as before stated, are mostly in the form of casts, have not been determined, but Prof. W. H. Dall, having cursorily examined them, formed a general impression confirmatory of the evidence established by the corals.

Prof. Gregory[2] mentions *Echinanthus* (or *Diplothecanthus* of Duncan) *concavus*, Cott. and *E. Antillarum*, Cott., sent by Mr. Forrest, as the first echinoids recorded as coming from Antigua, thus correlating the beds of this island with those of St. Bartholomew.

The eroded surfaces of these limestones give form to the hills, rising to 200 or 350 feet (one point to 456 feet) above the sea, with the gently sloping depressions between them. The higher portions of the hills appear not to have been subsequently covered by the accumulations about to be described. But the question of the erosion-features produced during the different periods since the early Miocene emergence of the limestones will be considered as a separate topic. I have refrained from comparing the age of the rock-formations and other features with their equivalents in the other West Indian islands, as this subject should form a chapter by itself.

The series has become a type in the Antillean islands, and may thus appropriately be called **the Antigua formation.**

VII. The Hodge's Hill Sandstones.

Hodge's Hill is situated at the north-eastern angle of Antigua, rising to a height of 154 feet above the sea. The exposed strata of this hill are composed of a creamy white calcareous sandstone. It is compact and suitable for building-material, hardening and darkening on exposure. The dip is in the normal north-easterly direction, but less than that of the White Limestones—not exceeding 10°. The rounded grains of calcareous sand give the

[1] [Since I sent in the manuscript of this paper, Dr. Vaughan has shown that the Antiguan coral-fauna is identical with that of the lower beds of the Upper Oligocene formation in South-western Georgia. See 'Science' n.s. vol. xii (1900) pp. 873–75.]

[2] Quart. Journ. Geol. Soc. vol. li (1895) p. 295.

rock an entirely different appearance from that of the White Limestones upon which it rests unconformably, as shown along the sea-coast west of the hill. At one point near here, the White Limestones were seen to form a sharp anticline, the eastern arm being much steeper than the western, the axis running north and south. The age of these beds has not been determined; but as they have been involved in the dislocation of the White Limestones, one suspects that the Hodge's Hill Sandstones belong to an epoch not long subsequent to that of the former rocks.

VIII. The Friar's Hill Series.

Lying on the eroded surface of the White Limestones at Friar's Hill is a thin layer of waterworn pebbles (formed out of the harder material of the underlying formation), succeeded by a bed of a homogeneous yellowish-white marl, 12 feet thick. In other artificial cuts in the hilly country, in the northern part of the island, as on the road to Millar's Mill, etc., one may observe the eroded surfaces of the underlying series, covered by a mantle of fragmental deposits of pebbles and marls not exceeding a thickness of 20 feet, except in buried depressions. The marly beds of the series are most frequently seen underlying the pebbles. The marls are in places indistinctly laminated, in others the stratification is shown only by lines of pebbles within the finer material. The bedding appears to be everywhere horizontal, although there are slight undulations (but not tilting). This deposit, whether marly or pebbly, is evidently one of mechanical origin, where the limestone has been more or less pulverized and rounded by the action of the waves. Occasional fragments of the older rocks have been seen included with other pebbles. The White Limestone-pebbles form a very considerable portion of the whole mass. On the gently-sloping hillside, from which the accumulation has not been entirely denuded, the finer marl has been so washed out as to leave the fields covered with a very stony surface—the pebbles being those left from the denudation of the overlying mantle. As the substance of these pebbles is identical with that of the underlying rocks, it is not surprising that they should not have been distinguished from disintegrated fragments of the older surface-rocks, but the intervening unconformity should have been recorded if not explained. Although they are waterworn, the soft materials of which they are composed do not become so well rounded or preserve their forms as do those of harder rocks. Furthermore, in places both the rounded pebbles of the upper series and the more angular surface-fragments of the limestones are intermingled; but where the waterworn pebbles are seen, they can usually be traced to lower altitudes, where their relationship to the typical deposits can be easily ascertained. The Friar's Hill Series is widespread, covering most of the lower slopes of this part of the island, and occurs up to an altitude of 200 feet, above which the hills of the older formation rise from 100 to 250 feet higher. This superficial mantle has been greatly denuded, so as to reduce its

thickness in places to only a few feet, or even to expose the underlying rocks, being, however, unmistakably preserved in the depressions of the older surface.

The materials of the Friar's Hill Series have not been transported to any considerable distance. For this reason, and on account of the fragmental character of the tuffs, as well as perhaps on account of the subsequent denudation, the evidence of the submergence to 200 feet, during this short epoch of rapid deposition, was not observed in the central portion of the island—unless it be in some of the cherty fragments (containing shells and petrified wood) scattered over the surface—where, however, the remains of a still newer deposit occur.

No fossils belonging to this formation [1] *per se* have been discovered as yet, but a few waterworn corals of the older beds occasionally are found among the pebbles. While the age cannot be determined from the included fossils, yet from physical considerations and from analogous accumulations with similar relationship—namely: the Matanzas formation of Cuba, the Layton of Jamaica, and the Lafayette of the American continent—the Friar's Hill Series is thought to belong to the close of the Pliocene or the early part of the Pleistocene Period.

IX. The Cassada-Garden Gravels.

Cassada Garden Estate is situated about 2 miles east of St. John's, on the eastern margin of the tuffs, and very near the south-western chain of hills of the White Limestone Series. Consequently, it is somewhat distantly removed from even the newer volcanic rocks of Drew's Hill. At the mill on Cassada Garden Estate is a low eminence rising only about 20 feet above the plain. A chain of similar mounds extends south-eastward. These are composed of somewhat coarse, perfectly waterworn pebbles of igneous rocks, with fresh, compact, undecomposed surfaces. In section, at the pond of Cassada Garden, the gravels are seen to be interstratified horizontally with loam. Mr. Watt, who kindly took me to this locality, had examined the section shown in the well, sunk through the deposit, and found that it did not exceed 20 feet in thickness, or precisely the height of the knolls above the plain. The gravel-knolls do not attain an elevation of more than 60 to 75 feet above the sea. These deposits, transported from considerable distances, and accumulated by currents, have also suffered denudation. The whole series resembles sections of the Columbia formation of America, the Zapata of Cuba, and the Liguanea of Jamaica, which belong to the early part of the Pleistocene Period.

X. Recent Deposits.

Many portions of the island adjacent to the sea-shore, as at St. George's Church, directly east of St. John's, have their surface

[1] [Some of the corals studied by Duncan may have come from these marls, or else from a still more recent formation not yet distinguished on this island, equivalent to the Usine Beds of Guadeloupe.]

covered with a thin layer of marly earth, containing a considerable number of marine shells, such as are now living in the adjacent sea. I observed the deposit, which is horizontally stratified, only to an elevation of 10 feet above sea-level. This surface was defined by M. Purves as a terrace of 'Horizontal Marls,' a feature of which, noticed by him, should not be passed over. In the upper portion of the accumulation he found a considerable number of land-shells, which had been washed down into the basins where the marls were formed. Among these shells he found *Helix formosa*, Férussac, to be the most abundant, but the shell no longer lives in this portion of the island, although it still survives in the mountain district of the south-western part of the island. He also found *Helicina Crosbyi*, Nob. now extinct, and known nowhere in the West Indies; and *Succinea Boonii*, Nob., a species no longer living. On account of these wholly or locally extinct species, although commingled with a number of living forms, he concluded that a considerable time has elapsed since the deposition of the beds containing them.

XI. Coral-Reefs.

Coral-reefs are extensively developed round both the islands of Antigua and Barbuda, rising to the surface of the sea, but they do not appear to form elevated reefs, characterizing the margin of the island. Even the low peninsulas and islands separating the bays on the north-eastern coast are composed of older formations, but the reefs in part obstruct the entrances of the bays or form 'keys' in them.

XII. Notes on Barbuda.

Before considering the erosion-feat s of Antigua, a word may be said with reference to Barbuda, which was involved in the denudation of the region. This island, nearly as large as Antigua, is a low undulating plain, passing into lagoons on its western side. The greatest elevation is only 115 feet. While I did not visit the island, Mr. Watt informed me that it was everywhere composed of a limestone, poorly covered with soil, and he kindly gave me fragments of the rock containing casts of old fossil shells, the whole apparently identical with the White Limestones of Antigua. This resemblance was also noticed by M. Purves. The collection of Nugent contained specimens from Barbuda, among which was *Cyphastræa costata*, Duncan, a form of coral occurring in the older Tertiary beds of Santo Domingo and Jamaica. Although the evidence of the identity of the rocks in the two islands is incomplete, yet there can hardly be any doubt of it, especially as they are not distantly separated, and the beds of the one island lie almost along the continuation of the strike of the strata in the other, but they may represent higher beds of the same series preserved from erosion. The recent formations, at most forming thin mantles, have not been studied. M. Purves states that the land-shells are identical with those of Antigua, except one variety of *Helicina*, thus indicating a late connection of the two islands.

XIII. Erosion-Features of the Antigua-Barbuda Region.

As before stated, these two islands and connecting banks form a geographical unit, although the greater part is slightly submerged. Whatever erosion had affected the mountain-districts of Antigua, prior to the elevation of the White Limestones, it left but little effect upon the later topography. The physical features of the north-western part of the island are such as show the former uniform thickness of the White Limestones from one end of the belt to the other. The surface gently descends in the same direction as the beds are inclined. At an elevation of about 100 feet is a peneplain sloping towards the eastern coast, but out of it rise isolated ridges. Following the trend of the belt, the country is characterized by a succession of hills, from 200 to 350 feet above the sea (which in one case only rise to 450 feet), separated by broad undulating depressions reduced to 150 feet above the sea. Thus we find that the atmospheric agents had not merely removed a great thickness of the White Limestones, but dissected the whole region and transformed the incisions into gently-sloping depressions, leaving only the higher points as isolated hills, occupying a subordinate portion of the country. One cannot even guess to how enormous an extent these rocks have been removed by degradation. They must have also covered to a greater or less extent the tuffs to the south-west. Such topography indicates the denudation of a region rising only gently above the base-level of erosion (that is, the level of the sea, the margin of which was then located at least beyond the banks); for the peninsulas of the eastern coast are the remains, in part, of the White Limestones separated by the excavation of the intervening valleys now submerged.

The configuration of Barbuda conforms to that of the north-eastern portion of Antigua; and the banks between the islands represent a coastal plain now submerged to 100 or 120 feet, which does not appear to have been subsequently modified by the growth of corals, as in the shallower water immediately about the islands.

The tufaceous deposits have evidently suffered a greater amount of erosion than the limestones, as the incoherent materials have been removed so as to form the low broad plains of the middle belt of the island, out of which some of the harder rocks, such as the remains of Drew's Hill, rise to elevations similar to that of the limestone-hills to the eastward; and indeed one eminence at the southern end of the belt (Monk's Hill) shows the remains of this deposit to an altitude of about 700 feet, indicating a differential denudation of nearly this amount.

The broad valleys of the lower reaches of the streams, with their low gradients, deeply indenting the mountain-zone, appear to belong to the same long period of denudation, but the deeper valleys of the interior of the island have quite different features, suggesting that during the long Miocene-Pliocene Period it was a plateau or mountain-area only partly dissected by the rapidly-

descending waters. As a broad feature of this old erosion, it may be mentioned that the wide shallow harbours, such as Willoughby Bay, Falmouth Bay, and Five Island Harbour, are only sunken portions of the land-valleys. But between these, which were once surrounded by high hills in the form of amphitheatres, and the low interior country, the elevated lands at their heads have been so reduced in height as to form low passes, leaving the sides of the valleys characterized by prominent elevations.

The broad undulating or rounded features were formed by atmospheric agents prior to the deposition of the Friar's Hill Series, which at most covers the old surface by only a thin mantle. Consequently, the island was continuously a land-surface from the early Miocene to about the close of the Pliocene Period, when it was again partly submerged during the Friar's Hill epoch. Throughout this long era, the topography of the region was a mountain-district, bordered by foot-hills of considerable elevation, among which was the adventitious volcano of Drew's Hill, and perhaps later a volcanic outburst at Crosbie's,[1] beyond which the coastal plains extended to the edge of the banks north of Barbuda.

After the Friar's Hill epoch, subsequent erosion produced other characteristics throughout the region. The broad depressions indenting the margins of Antigua were greatly deepened and extended farther into the highlands. These valleys, on the coast, are now drowned to a depth of 40 or 50, and in one case to 80 feet. On the southern coast the channels of Willoughby Bay and English Harbour are distinctly traceable to a depth of 100 feet, and that of Falmouth to 140 feet, within the limits of the less submerged banks. Similar trenches can be traced upon the submarine plains between the two islands, having a depth of 25 or 40 feet, and in a locality west of Barbuda there is one of 100 feet below the surface of the banks, which are themselves submerged only 80 feet. Where the margins of the submarine plateau have dropped to 150 feet and more below the surface of the sea, they show valley-like indentations trending to those of the land. One of the most conspicuous occurs west of Five Island Harbour. It reaches a depth of 1290 feet within the line where the banks are covered by less than 150 feet of water. This deep amphitheatre opens out into the broad submarine valley, where the soundings reach over 1900 feet. Broad embayments encroach upon both sides of the plateau between Antigua and Barbuda, thus considerably reducing its breadth.

I have just mentioned comparatively narrow channels upon the surface of the submarine plateau, and deep indentations into its margin. The former feature may be produced either where the land has no great altitude above the drainage-level, or upon the surface of a high plateau, sufficiently far within its margin for the streams not to be affected by the deep declivity of its edge.

[1] This is a dolerite containing far more pyroxenic elements than that of Drew's Hill, one of the facts which led M. Purves to infer its more recent origin.

The second condition is the result of atmospheric denudation and rapidly-descending streams, producing deep valleys, headed by amphitheatres, which are constantly receding into the highlands, and cause the shallow channels upon the surface to become eventually transformed into cañons and valleys dissecting the plateau.

The difference between the erosion-features of the Miocene-Pliocene and the early Pleistocene Periods (separated by the Friar's Hill submergence) lies in the low undulating topographic forms of the first-mentioned, requiring a long period of development at a low elevation; and the deep valleys and sharp outlines of the latter, produced rapidly at considerable heights above the drainage-level of the region. But it should not be forgotten that the valleys on the high tablelands, well within their borders and not affected by the declivity of their margins, may still preserve the flattened features of a lower level of erosion.

The erosion-features of the higher parts of the mountains of Antigua—highlands dissected into narrow ridges and deep valleys of great declivity—are the result of the older degradation continued to the present time without interruption by submergence. This complete dissection of the mountain-districts is an illustration of the effects which would have been produced upon the Antigua-Barbuda plateau had the secondary period of denudation under conditions of great elevation been continued sufficiently long.

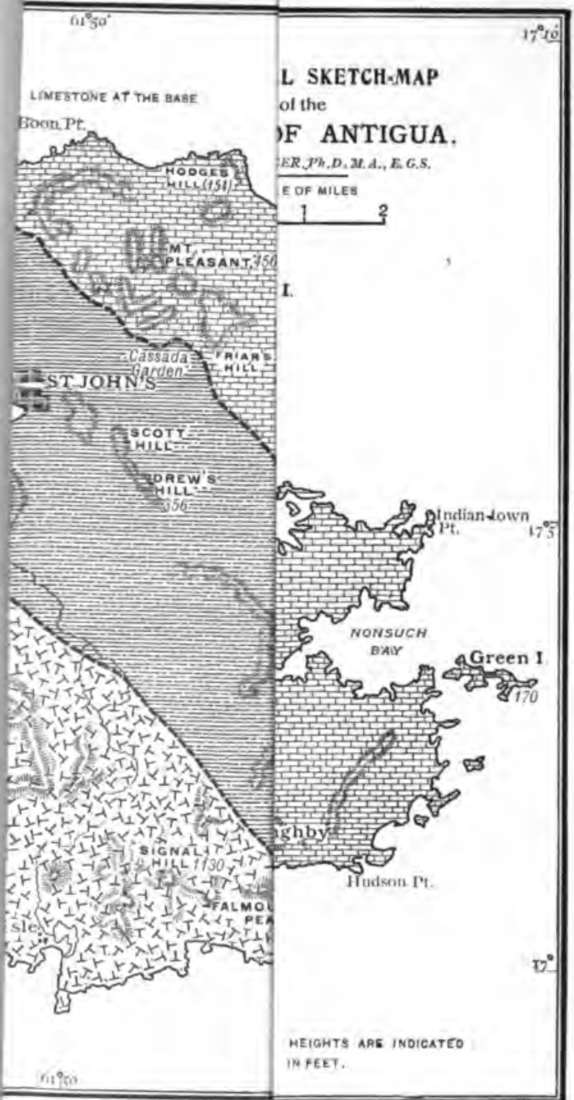
A considerable portion of the Friar's Hill Series was removed during the early Pleistocene elevation. Again there has been a certain amount of denudation since the epoch of the Cassada-Garden Gravels, and also since the accumulation of the low marls on the eastern coast, this latter extending below sea-level.

The relative amount of work during the last episode is not so well defined in Antigua as in other islands, and deserves further study in the field.

XIV. Summary and Conclusions as to Changes of Level of Land and Sea.

As has already been shown, this region was an extensive land-surface during the Miocene-Pliocene Period, which was eventually reduced to a comparatively low elevation above sea-level before the close of that time. This is the conclusion arrived at from the evidence within the boundaries of the submerged plateau, surmounted by the islands of Antigua and Barbuda. But outside the limit of this paper there is evidence that leads me to think that during the earlier part of the period the whole region was at least 2000 feet higher than now, when the broad valleys between the Antiguan mass and the neighbouring islands on the submarine Antillean plateau were being fashioned out of a higher tableland: of this a remnant remains in the Antigua-Barbuda plateau, the surface of which was reduced to its present form in the latter part of the period. I have not observed in Antigua the evidence of an insular elevation, as seen in the islands where late volcanic

Soc. Vol. LVII, Pl. XV.



activity has prevailed, but this is a question for consideration when studying the general changes of level of the Antillean plateau.

The Miocene-Pliocene elevation in Antigua was followed by a submergence (the Friar's Hill) to a depth of 200 feet below the present altitude. On this account it is possible that the mechanical accumulations of Antigua are represented in Barbuda by calcareous beds containing a recent type of organic remains.

Following this submergence about the close of the Pliocene Period, the land rose to a great altitude. The evidence from the dissection of the banks shows the elevation to have reached 2000 feet. But the submarine plateau between Antigua and Guadeloupe is further incised by channels, indicating the elevation to have exceeded 3000 feet. This is not the extreme height to which the region rose, but the evidence lies beyond the province of this paper. These conditions did not continue sufficiently long to complete the dissection of the tablelands, and consequently the Antigua-Barbuda mass remains intact. This elevation (subsequent to the deposition of the Friar's Hill Series) was in the early part of the Pleistocene Period, fuller evidence of which occurs elsewhere.[1]

Then followed a subsidence, which culminated in a submergence to a depth of 75 feet when the Cassada-Garden Gravels were deposited, to be succeeded by a re-elevation—not merely to this amount, but to 100 feet or more—when the shallow channels on the submarine bank were formed. This feature would be in harmony with the later movements observed in other islands. Sufficient study has not been given to the subject to determine whether the recent marls on the eastern coast were laid down during the post-Cassada Garden emergence—in which case they were once considerably higher before sinking to the present level—or whether they belonged to a later episode indicating another subsidence and re-emergence to a height of 10 feet. However, a doubt is cast upon a very recent re-emergence, on account of the considerable age of the shells in the marls, and also because recent corals do not occur in the raised reefs.

EXPLANATION OF PLATE XV.

Geological sketch-map of the Island of Antigua, on the scale of about 2¼ miles to the inch.

A south-western mountain-zone composed of old igneous formations; a central rolling valley-belt with undulating hills, formed of tufaceous deposits; a north-eastern hilly or rolling country underlain by early Tertiary (Eocene-Oligocene) White Limestones, whose eroded surfaces are often succeeded by a denuded mantle of the Friar's Hill Series of marls. There are also isolated patches of a later formation of gravel, as at Cassada Garden.

---

[1] See 'Reconstruction of the Antillean Continent,' Bull. Geol. Soc. Am. vol. vi (1895) pp. 103–40; 'Geographical Evolution of Cuba,' *ibid.* vol. vii (1896) pp. 67–94; and 'Late Formations & Great Changes of Level in Jamaica,' Trans. Canad. Inst. vol. v (1898) pp. 325–58.

31. *On the* Geological *and* Physical Development *of* Guadeloupe.

By Prof. Joseph William Winthrop Spencer, M.A., Ph.D., F.G.S. (Read April 24th, 1901.)

Contents.

I. Introduction.

My visit to Guadeloupe in March, 1897, was for the purpose of extending my observations of the later geological features of the Antilles southward from Antigua; especially those bearing upon the changes of level of land and sea since the early Miocene Period, and their necessary variation in adjacent localities.

The features of the Guadeloupe archipelago present some striking contrasts to those of the Antigua-Barbuda plateau. The main island is divided into Guadeloupe and Grande Terre. The former is traversed by high mountains, surmounted by recent volcanoes, which are unrepresented in Antigua; but all these features are reproduced in Dominica and other islands of the western belt of the Lesser Antilles. Grande Terre is a limestone-country comparable with Antigua, and, therefore, forms the principal subject of this paper.

The islands of Désirade, Petite Terre, Marie Galante, and The Saints, belong to the same physical unit as Guadeloupe—the three former having characteristics similar to those of Grande Terre, and the last, a group of seven islands, are remnants of the older volcanic rocks. This archipelago is dissected to much greater depths than the Antigua-Barbuda plateau, and shows modifications in the erosion-features, helping us to further understand the history of the Antillean plateau, most of which is now submerged.

The earliest geological contributions appear to have been those of William Maclure,[1] shortly afterwards followed by the writings of Alexandre Moreau de Jonnès.[2] Maclure's paper, along with the

[1] Journ. Acad. Nat. Sci. Philad. vol. i, pt. i (1817) p. 134.

[2] 'Histoire Physique des Antilles Françaises' Paris, 1822.

studies of Pierre Duchassaing,[1] constitutes our principal knowledge of the Tertiary formations of Guadeloupe, and will be referred to in the following pages.

II. Situation and Physical Characteristics.

The nearest point of Grande Terre is 36 miles from Antigua, from which it is separated by a broad depression in the Antillean plateau, submerged to a depth of about 2000 feet, out of which rises an intermediate island now sunk to a depth of 300 feet.[2] This submarine ridge is dissected by channels and indentations, reaching to depths between 2400 and 3000 feet below sea-level. The characteristics of the drowned valleys of the Guadeloupe archipelago will be considered under the heading of erosion-features. The southern part of the group is separated from Dominica by a submarine depression about 17 miles wide, having a depth of 2100 feet, but this is further dissected so that the indentation, south of The Saints, is found to reach a depth of 3294 feet.

Grande Terre has a triangular form, composed of three lobes. It is about 18 miles from north to south, with a somewhat greater transverse diameter; but it is so deeply indented as to reduce the area to 217 square miles. It is an undulating limestone-country, the northern lobe being separated from the more southern portion of the island by a plain or valley, reaching to a width of 2 miles, and of an elevation generally less than 50 feet above the sea. This extends north of west from Moule across the island. North of the depression, from near Port Louis extending eastward, is a limestone-escarpment, crossing the island, and rising 150 feet above the low country, or 200 feet above the sea. One point on this northern plateau rises to 279 feet. South of the great depression, the central portion of the island is broken into valleys and hills, one point rising to 354 feet. Thus there is a general resemblance in Guadeloupe, even as to height, with that district of Antigua which is underlain by the White Limestones. Natural rock-exposures are relatively few, as the surface is generally covered deeply with soil.

Guadeloupe proper has the form of an ellipse, with a length of 28 miles, a breadth of 14 miles, and an area of 365 square miles. The high mountain-ridge traversing it is surmounted by four volcanic cones, the highest of which is 4868 feet. The descent of the mountains to the west is rapid, leaving little or no low land between their base and the coast. Even the delta-flats at the end of the short steep valleys are insignificant. However, the high

[1] Bull. Soc. Géol. France, ser. 2, vol. iv (1847) p. 1093, & *ibid.* vol. xii (1855) p. 753. A note by Payen will be referred to later (p. 515). A contribution by A. Damour is found in Comptes Rendus Acad. Sci. Paris, vol. li (1860) p. 559; also Charles Ste.-Claire Deville published a 'Voyage Géologique aux Antilles' in 1848–59: but I have not seen the two last-mentioned works.

[2] See U.S. Hydrographic Chart No. 40, or the corresponding British Admiralty Chart.

coast-line appears to be bordered by a narrow plain, now submerged, but deeply indented by ravines. The eastern side of the mountain-range descends less rapidly than the western side, having larger and more important valleys.

Grande Terre and Guadeloupe proper are almost divided by the broad bays, called 'Grand Cul-de-Sac Marin' and 'Petit Cul-de-Sac Marin.' They are separated by an isthmus about 3 miles across, which is traversed by a narrow strait (from 100 to 400 feet wide) called Salt River. These shallow bays are more or less obstructed with recent coral-growths. The isthmus is only a few feet above sea-level, but it is bounded by low escarpments about 3 miles apart, that on the eastern side being of limestone.

III. Notes on Guadeloupe proper and the Basement of the Island.

The oldest rocks in Guadeloupe may be seen along the flanks of the mountains. There are evidently several formations, varying in age from that of the old eruptive foundation to the recent volcanic accumulations, some of the intermediate deposits being of mechanical origin, derived from the older igneous rocks. There are also a few remnants of calcareous beds. Seen to an altitude of about 1200 feet, along the road east of Basse Terre, there is an old conglomerate composed of angular and subangular fragments of volcanic rocks. Beyond this summit, and at various elevations down to near sea-level, there are recurring exposures of red residual soils, having a depth of more than 20 feet, which have been derived *in situ* from the old eruptive rocks. Near Trois Rivières is an underlying sandy tuff, in well-marked beds which are thrust up into an anticline. This tuff is probably the equivalent of the yellow tuff and volcanic sand underlying the limestones of Grande Terre, though the beds are not continuously traceable. Two miles north of Capisterre (which is on the south-eastern coast), and at various points to beyond the isthmus, one may see the interrupted exposures of loams and gravels which constitute a formation more recent than the limestones of Grande Terre. These accumulations, as well as the gravels about Basse Terre and some fragmental remains of limestones, will be referred to again (p. 513). The recurring exposures of residual soils, the loosely compacted tuffs laid down beneath the sea, and the loams and gravels, are due to the relative amount of erosion of the land-surface in late or recent geological times.

At the northern end of the island, and thence westward to Port Deshayes, are thick beds of compact volcanic tuffs, containing numerous small fragments distributed irregularly through the fine materials of the beds, and large boulders; but the strata are often so distributed as to make their dip undeterminable. These same beds are seen, with some interruptions along the western coast to south of Bouillante, where they vary in position from horizontal to an angle of 20°. They rest upon a basement of eruptive rocks with denuded surfaces. The age of these tuffs, and that of the

conglomerates above Basse Terre, is undetermined. They cannot be correlated with the submarine tuffs observed in the south-eastern part of the island, nor is it known whether they are older or newer. They may be contemporary with other kinds of Tertiary accumulations in Grande Terre. However, the observations show the great age of the underlying eruptive rocks, which are evidently as old as the igneous basement of Antigua, or of pre-Tertiary age. Such igneous and igneo-mechanical formations have been more fully studied in Dominica.

As the old eruptives underlie the tuffs near Trois Rivières, the apparent representatives of which were long ago described by Moreau de Jonnès and Duchassaing as underlying the limestones of Grande Terre, there is little reason to doubt their extension under the whole island, or even under the archipelago.

The outwardly-sloping terraces, observed in places up to a considerable elevation, are simply the massive beds of tuff, giving rise to cliffs, 100 feet high, which have been deformed owing to the elevation of the mountain-mass due to volcanic forces. These have not affected the strata or configuration of Grande Terre. The late volcanic phenomena have not been studied by me, but eruptions were recorded at several dates in the eighteenth and nineteenth centuries.[1]

IV. The Earlier Tertiary Formations in Grande Terre.

The lowest beds in Grande Terre are seen in only a few localities at low elevations, beneath the overlying limestones east of Salt River. They are composed of yellow tuff, surmounted by 75 or 80 feet of volcanic sand redeposited by the sea, as described by Moreau de Jonnès and Duchassaing. In the lower beds those observers found only a few fossils, but in the upper layers Duchassaing obtained *Arca umbonata*, *Pectunculus pulvinatus*, Lam., *Cyathina guadalupensis*, and other organisms. The *Pectunculus* is an European Eocene type, and *Cyathina* may be placed along with the corals of Antigua, thus suggesting the early Tertiary age of the strata. Conformably with these beds, and underlying most of the surface of Grande Terre, there is a calcareous formation consisting of beds of white or creamy limestone and marl, with the surface sometimes weathered to drab. Some of the beds are fine-grained, compact, and hard, others are earthy and marly. In places they contain fossils, mostly in the form of casts. The rocks of more compact texture often abound in cavities. The strata are nearly horizontal, but dip north-eastward. These beds include the roches à ravets and part of the white marls or foraminiferal limestones of Duchassaing.[2]

[1] In 1778, 1796, 1797, 1836, 1837, & 1846.

[2] Duchassaing classified the formations of Grande Terre as follows:—

Newer Pliocene: Alluvium and detrital formations, the Madreporic, and the Galibis or Anthropolite.

Older Pliocene: Clays; and white marl or foraminiferal limestone.

Miocene: Roches à ravets, volcanic sands, redeposited by the sea, and yellowish tuffs. See Bull. Soc. Géol. France, ser. 2, vol. iv (1847) pp. 1094–95.

Section of Guadeloupe from Basse Terre north-eastward to near Port d'Enfer; distance 38 miles.

From C to A is Guadeloupe proper; A to A' is lowland and sea; A' to B is Grande Terre.
Mass OI=old igneous foundation penetrated by late volcanic eruptions.
V=summit of cones (reduced in height).
OT=marginal coping of central mass by old tuffs, conglomerate, etc.

g=late gravel at Basse Terre.
tt=stratified tuff.
L L=White Limestone (Eocene-Oligocene).
U=Usine Limestones (south of line of section, late Pliocene?).
F=Lafonde Marls, unconformable upon the White Limestone (late Pliocene?).

PB=Petit-Bourg Series, the two members not being distinguishable, except where the unconformity is shown. Off the line of section, on Guadeloupe proper, there are a few fragments of marls older than the Upper Petit-Bourg Series.

He includes in this last formation the marls upon the hills, the limestones in the escarpments, and other calcareous exposures at lower altitudes. This has given rise to difficulty in determining their age: for, upon some of the hills there is an unconformable marl, much newer than the strata in the escarpments, a fact apparently unnoticed by him; and again the beds at low altitudes, containing the modern types of organisms, are much more recent than the age which he assigns to this formation — the older Pliocene. (Moreau de Jonnès did not regard all of these deposits as so recent.) From the fauna of the volcanic sands, and from nearly the same which he found occurring in the lower limestones (roches à ravets), including a *Terebratula*, Duchassaing concluded that all the lower beds mentioned belonged to the Miocene Period.

The fossils in the limestones are poorly preserved, but among the few

ˋcted near Les Abîmes there is a species of coral of ·hora, which is an Oligocene or Miocene form (*teste* ˋese limestones, with the underlying tuffs, appear at geological system belonging to the older ·e as the similar succession of like tuffs and It may be noted that the systems of the along the strike of the beds in both, than 35 miles. There is no reason to doubt nditions of Antigua were reproduced in, or , Guadeloupe, by way of the intermediate bank d. Accordingly we may designate this series as the ormation.

V. The Lafonde Gravel and Marl.

On the plateau above the escarpment, which extends from Port Louis to the eastern coast, occurs a deposit of white marl with waterworn gravel, derived from the adjacent limestones mentioned in the cliffs of the escarpment. I have designated this superficial marl, resting on the older strata of similar composition (and often unrecognizable from them, where the gravels and the unconformity are both wanting or concealed), the Lafonde Series, after an estate at the foot of the escarpment. This deposit is only a few feet thick, and rests upon the eroded surface of the White Limestone Series, but in horizontal layers, the lamination being shown by the lines of pebbles. In places, the well waterworn gravels are mixed with the angular fragments of the disintegrated rocks of the underlying beds, where the more marly earth has been washed away. These loams and gravels were observed at an elevation of 200 feet.

I did not attempt to follow out the distribution of the Lafonde Series in Guadeloupe, but only sought to find the recurrence of the Friar's Hill Series, of Antigua, with the results stated, showing that the thin mantles in both islands have precisely the same characteristics and elevation (200 feet), and rest unconformably upon the white limestones of the Upper Oligocene or Lower Miocene system.[1]

VI. The Limestones at the Usine of Pointe à Pitre.

Adjacent to the sea-shore, at the Usine south-east of Pointe à Pitre, is a cliff rising to a height of 40 feet. It is composed of a creamy white, compact limestone in horizontal beds, containing numerous fossils, mostly in the form of casts, many of which are scarcely determinable. But on making a preliminary inspection of my collection, Prof. W. H. Dall considered that the fossil shells were mostly recent species. Two corals, obtained in these beds, were kindly determined for me by Dr. T. Wayland Vaughan—

[1] The character and position of these beds are the same as those of the Matanzas Series of Cuba, the Layton of Jamaica, and the Lafayette of the American coast; the age of these is found to be older than the Glacial deposits, but there are no extinct forms among the few fossils contained in them.

namely, *Orbicella cavernosa*, Linn. and *O. acropora*, Linn.—which are living species, indicating an entirely different coral-fauna from that of the typical Oligocene Period of the West Indies. Besides the shells collected by myself, others were kindly given to me by M. Louis Guesde, apparently from the same kind of rock, but from unknown localities.

Here then, at Pointe à Pitre, is a formation, in appearance much like the older limestones (although more sandy and more uniformly hardened into a compact rock), but far richer in fossils, assignable to a different fauna. The contact of this outcrop with the lower beds was not observed. Duchassaing gave a list of twenty-six molluscs, thirteen echinoderms, and eight corals, as being derived from his upper calcareous marl. All the corals are living, so too probably most of the molluscs, but only seven of the echinoderms. And he notes an abundance of polyzoa and foraminifera (*Lunulites*). This admixture of the foraminifer *Lunulites* (not differing from *L. umbellata* of the Paris Basin) and extinct echinoderms, and perhaps some molluscs, with forms now living, especially the corals, suggests that his collections were obtained from different horizons. This supposition seems probable, as his studies were centred in the low district of Moule, where later deposits than even those of Pointe à Pitre occur.

From the general character of the beds at the Usine, such as the consolidation of the materials into hard rocks, the complete fossilization of the organic remains now preserved as casts, etc., and the very great erosion which they have undergone since their emergence, they must have a considerable antiquity. But on account of their containing modern fossils, I would provisionally place them at the close of the Pliocene or commencement of the Pleistocene Period, of nearly, if not quite, the same age as the Lafonde Series. The different character of the Usine Limestones and the Lafonde Series may be explained by the fact that at Lafonde the country was submerged 200 feet, which still permitted of the small rocky islands supplying the materials for the loams and gravels round their shores; while in deeper water and at a distance seaward from the few remaining islets, the organic remains, and the sands derived from them, would be the only source of supply for the rock-making materials, and thus the exclusion of the fragmental remains. But the Usine strata represent a deeper and longer submergence than the Lafonde Marls, which have been greatly denuded.[1]

VII. Late Deposits and Coral-Reefs in Grande Terre.

Raised coral-reefs occur on the eastern coast, as at Moule, up to a height of 6 or 8 feet above sea-level. They contain several

[1] [From recent studies in Barbados it is now suggested that the Usine Limestones may be either a deposit representing the continuation of the Lafonde epoch, or even one subsequent to it and belonging to the earlier Pleistocene Period. The phenomena appear to be repeated in Anguilla, Sombrero, St. Kitts, Dominica, etc.]

species, which are all recent. It was in this district that the beds containing human remains were found. These are consolidated calcareous sands, to which Duchassaing gave the name of the Galibis or Anthropolite formation, and which he considered as contemporary with the coral-reefs now raised a few feet above the sea.[1]

The alluvium was described by Moreau de Jonnès. Duchassaing says that it contained *Succinea cucullata*, then very rare among the living forms. Neither these nor the thin layers of unfossiliferous clays beneath, mentioned by Duchassaing, were studied by me in Grande Terre.

VIII. The Petit-Bourg Series.

Along the eastern coast of Guadeloupe proper, from near Capisterre to beyond the isthmus, I have seen recurring deposits of loams and gravels. One of the best exposed sections occurs at Petit Bourg, where the cliffs rise from the seashore to a height of 40 or 50 feet. At the bluff north of the village, sandy tuffs, like that near Trois Rivières, form the base. Upon its eroded surface lies a deposit of coarse, well-rounded, waterworn gravel, which, where not denuded, has a thickness of 10 feet or a little more; but its surface is greatly eroded, so that at the southern end of the section it is entirely wanting. Succeeding the underlying beds unconformably, whether gravel or tuff, is an upper loam, indistinctly laminated, except where it contains lines of pebbles. The more restricted exposure east of the village consists of about 10 feet of the upper loams, resting upon 10 feet of the coarse gravels (containing occasional volcanic bombs 12 inches in diameter), beneath which comes another unconformable bed of red loam, exposed to a depth of 20 feet.

The country between Petit Bourg and the Salt River is characterized by the remains of a base-level of erosion or peneplain, with the rounded hills rising from 50 to 100 feet above the sea. These consist of red loams and waterworn gravels, or where they have been washed away to a sufficient depth, the more ancient residual clays may form the surface. In some of the more massive hills and deeper cuts are large deposits of rounded gravel, resting upon the weatherworn surfaces of loams or in other places of tuff. These gravels contain volcanic bombs and angular fragments, evidently the product of some volcanic eruption, during which the ejectamenta were thrown into the sea in which the gravels were being deposited. These hills, composed of loams and gravels, are the continuation of the deposit at Petit Bourg, but the intervening

[1] Duchassaing thought that the human remains found (on the estate, at that time, of MM. Morrel), near Moule, belonged to a race antecedent to the Caribs. The word Galibis was taken from the old Carib name for the island, Bull. Soc. Géol. France, ser. 2, vol. iv (1847) p. 1096.

depressions show the surface of the country to have been greatly denuded. There are evidently two formations overlying the volcanic tuffs, each of loams and gravels with the pebbles of the upper series of smaller size, while the lower gravels are coarse and exposed only in sections along the coast or in the interior of the hills where access has been had to them. The upper deposits form a mantle over both the high and low ground, and have not been nearly so much denuded as the lower. Between Petit Bourg and Salt River, these mechanical formations rest upon white limestones, rising only in a few places above the sea. All the strata, whether limestones or loams and gravels, lie almost horizontally, dipping very slightly north-eastward. Accordingly, the outlying limestones west of the isthmus are the equivalent of those of Grande Terre, but separated by the broad shallow depression, occupied by the isthmus (2 or 3 miles across), excavated when the country was reduced to near the base-level of erosion, before the deposition of loams and gravels which lie on it. From all these facts it appears that both members of the Petit-Bourg Series are relatively of late origin.

The occurrence of these two mechanical deposits, composed of the same materials, is only a repetition of the phenomena of the Lafayette and the Columbia formations of the coastal plains of North America, where the component materials can scarcely be distinguished, except by the unconformity, etc., which represents an enormous physical break in their succession. The accumulation of the Lower Petit-Bourg Series in the same position as that of the Lafonde is what might be expected, owing to their both being the succeeding beds deposited upon the surface of the country, subsequent to the denudation of the Miocene-Pliocene Period. The Petit-Bourg gravels are situated at the foot of hills, supplying eruptive materials for the loams and pebbles, while the Lafonde gravels are derived from limestones of the small islands remaining above water during the submergence of this epoch. From the erosion-features it is manifest that the upper series of loams and gravels are very much newer than the lower, and occupy the same horizon as the Cassada-Garden Series of Antigua, or the Columbia Series of the American continent.[1]

The loams appear to be derived from the pre-existing residual soils, such as those mentioned, and the upper loams and gravels seem to have been the material of the lower series worked over again.

In the weatherworn terraces above Basse Terre, upon the south-western side of Guadeloupe proper, thin beds of gravel occur up to an elevation of 250 feet. This superficial mantle has not been connected with the Petit-Bourg Series, but it has the general

[1] These are also represented by the Zapata Series of Cuba, and the Liguanea of Jamaica. Furthermore, a corresponding formation is found in St. Martin, St. Kitts, etc.

appearance of that of the Lower Petit-Bourg Series. The extreme elevation of the gravels on both sides of the island may be somewhat greater than that of the exposures visited, and if there are higher sections observable, I should expect them to occur near the seacoast in the vicinity of Trois Rivières. On the eastern flanks of the mountain-country they are apt to be concealed by the creep and washes of the soils.

IX. Other Calcareous Fragments in Guadeloupe proper.

Payen[1] mentioned the occurrence at Vieux Fort, near Basse Terre, of two beds of limestone: one at an altitude of 330 feet above the sea, resting horizontally on a volcanic foundation, the other at an elevation of 130 feet. Deshayes found that the fossils contained in them belonged to living species of shells and echinoderms, and concluded that the beds were Quaternary. Duchassaing also mentions the occurrence of limestones near Trois Rivières.[2] I was in both of these neighbourhoods, but not having seen the original papers at that time, mentioning the localities, I could learn nothing of them from enquiries made of most likely persons, as but little interest or observation was manifested in the scientific features of the island. The calcareous beds described near Basse Terre seem to be reproduced in Dominica, and these I have studied.

X. Remains of *Elephas*.

In the Library & Museum Building at Pointe à Pitre, M. Louis Guesde kindly showed me the tooth of a small species of *Elephas*, which had been found in Grande Terre. It was 6 inches long, and upon the serrated crown it measured 5 by 2 inches. It appears to be something like the small Maltese type, and its occurrence has an important bearing on the question of the elevation of the Windward Island chain.

XI. Erosion-Features.

The erosion-features of Grande Terre are characterized by undulations, where the rounded hills rise from 50 to 100 feet above the broad depressions separating them. As we have seen, the foundations of the country are carved out of the earlier Tertiary Limestones, except on the isthmus between the two parts of Guadeloupe and the adjacent district, where they have been washed away, so as to expose the underlying tuffs. The peneplain, to which the surface of Grande Terre and of a part of the main island was reduced, extended broadly beneath the now shallow bays north

[1] Bull. Soc. Géol. France, ser. 2, vol. xx (1863) p. 475.
[2] *Ibid.* vol. iv (1847) p. 1097.

and south of the isthmus. This is also seen in the great banks reaching to Petite Terre and Désirade, and about The Saints and Marie Galante. The high bluffs of 100 or 150 feet along the eastern coast and other points are the results of the recent encroachments of the sea; but the interior escarpment in the northern part of the island is a somewhat older feature. Undulating outlines are characteristic of the denudation of a country near the base-level of erosion, lasting throughout a long period. The duration of land-surfaces in Guadeloupe continued from the time of the early Miocene emergence until that of the introduction of recent types of life, or throughout the Miocene-Pliocene Period. The condition of low elevation of the country mentioned, which obtained during the latter part of the period, does not appear to have prevailed during the whole time; for we find the sunken plateau connecting the islands having the form of broad depressions or undulating plains like those of base-levels of erosion, though now 2000 feet below sea-level. The drowned plains and ridges are modified by the deep channels, some of which continue upward and extend to the deep indentations of the island-plateau formed by streams descending torrentially from tablelands.

The recurrence of the Tertiary Limestones, etc., on several of the adjacent islands suggests their late continuity. That the archipelago of Guadeloupe was not bodily thrust up above the submerged ridge by volcanic forces is shown in the physical difference between the main island and Grande Terre, where the latter, as has been seen, was not deformed, while the volcanic forces have only lifted the high mountain-ridges where there has been late activity, and have not differentially raised the islands in other districts which are characterized by old eruptive basements. Upon this hypothesis, the earlier Miocene-Pliocene elevation of Guadeloupe, during the formation of the broad depressions between the islands, reached an altitude of at least 2000 feet above that of the present day (except the volcanic mountains of more recent date). Then the Guadeloupe archipelago stood out as a plateau, like much of recent Jamaica, with its escarpments and surfaces broken by atmospheric denudation.

The greatest of the broad valleys indenting the mass is that between Marie Galante and Grande Terre. With the gradual subsidence of the plateau, the encroachments of the sea modified the now submarine escarpments, and eventually brought the tableland so low that the recent features of Grande Terre could be produced; but this comparatively low altitude must have been of long duration to have allowed of the moulding of the rounded topography.

Then followed the submergence to a depth of 200 feet below the present height, with the accumulation of the Lafonde and Lower Petit-Bourg Series, which was a comparatively short interval. This episode was about the close of the Pliocene Period; after which there was another epoch of very great elevation and rapid denudation, since the introduction of the recent fauna of the Usine Limestones,

when the Lower Petit-Bourg and Lafonde gravels were largely removed by denudation.

The evidence of this great elevation is shown in the comparatively narrow, but very deep valleys, dissecting the older rounded topographic forms. Thus, between The Saints and Guadeloupe is a narrow valley less than 2 miles in width, reaching to a depth of 900 feet, or 700 feet deep in the submerged plain or bank. It deepens to 1200 feet a few miles westward, beyond which it attains a depth of 3000 feet. The data for determining the depth of the channel, through the embayment of earlier origin, between Marie Galante and Petite Terre, have not been obtained, though it is known to be greater than 2000 feet. Between the south-eastern extremity of Grande Terre and Désirade, where the plains are sunk to only 66 feet, there is an amphitheatre or cirque, with a depth of 990 feet, deepening to 1122 feet, and farther seaward to 1720 feet, beyond which no soundings have been taken. The valley between The Saints and Marie Galante is now drowned to 792 feet, and the descent to the broad depression beyond is very rapid.

The deep indentations of the sunken border of the western side of Guadeloupe proper tell the same story of a former great elevation, when the gorges were being channelled out by rapidly-flowing streams. Thus, north of Basse Terre there is an indentation with a depth of 810 feet within the limit of the coastal plain. Opposite Ferry Point, a depth of 1740 feet is reached within the limits of the submarine bank, where it is covered by only 246 feet of water. At the north-eastern angle, there is another valley seen at 1980 feet. South of The Saints, and between them and Dominica, the channel reaches to a depth of 3294 feet, indenting the submerged ridge between the two islands. This is the height to which the region was elevated so far as the evidence directly obtained from Guadeloupe bears testimony, but a much greater altitude is indicated beyond the immediate area.

The epoch of great elevation and stupendous erosion, culminating in deep valleys, was in the early Pleistocene Period, after the introduction of recent types of life; but from the evidence of the deposits on the American continent, with similar geological associations, it was during, or prior to, the early Glacial time. It may be added, parenthetically, that to this epoch the abrupt features of the escarpment east of Port Louis owe their origin, when the streams on the tableland began to deepen their courses.

Then followed a subsidence, during the accumulation of the Upper Petit-Bourg Series, to a depth of 100 feet or perhaps somewhat more. The depressions now forming the isthmus became covered with the mantle of the loams and gravels of this series—a Mid-Pleistocene deposit.

The succeeding rise of the land carried it above the present height, when the rapid streams made channels across the plains, now covered by the two very shallow bays north and south of the isthmus, containing many islets, some of which are the remains of

the Petit-Bourg Series, etc. These drowned watercourses have a depth of 40 to 60 feet, but near the margin of the sunken terrace are gullies or cañons, reaching a depth of 100 to 150 feet, where the neighbouring shoals are not covered by more than 1 to 6 feet of water, showing that the elevation reached this amount, while there was a considerable removal of surface-loams. Yet the epoch was not one of long duration, and in no way comparable in denudation to the epoch preceding it.

Another subsidence of the land brought it down to about the present level, although the reefs on the eastern coast are raised to a height of 6 or 8 feet, suggesting a subsidence to that amount below the present surface, and subsequent re-elevation; but the small oscillations of late date may be more or less local.

The erosion-features of the mountain-mass are largely recent, without the mass being deeply dissected by the torrential streams. But the present volcanic activity dates back to the Lower Petit-Bourg stage—close of the Pliocene (?) Period—prior to which the mountains may have been no higher than those of Antigua.

XII. Marie Galante, Désirade, Petite Terre, and The Saints.

Long ago William Maclure reported the first three of these to be limestone-islands, and we may infer from their position that their history is doubtless that of Grande Terre. Désirade has a height reaching to 912 feet, and Marie Galante attains an elevation of 672 feet, while Petite Terre is scarcely more than a low bank. The Saints are old volcanic formations with the highest points reaching 1035 and 932 feet. All these outliers are much dissected by the atmospheric forces, still very active, owing to the great declivities of the land.

XIII. Summary and Conclusions as to Changes of Level of Land and Sea.

(1) A land-surface throughout the Miocene-Pliocene Period, with an elevation during the earlier days amounting to 2000 feet or more above the present height (except the later volcanic mountain-ranges), during the formation of the broad depressions between the islands; followed by a sinking of the land to somewhat near the present altitude, and the formation of the undulating surface of Grande Terre.

(2) A submergence to 200 feet at about the close of the Pliocene Period, with the accumulation of the Lafonde and Lower Petit-Bourg gravels and loams and the Usine Limestones (?).

(3) A re-elevation to about 3000 feet, shown within the region of the archipelago—but this is only a small portion of the extreme height indicated outside of the group—in the early Pleistocene Period, with the formation of deep valleys and amphitheatres dissecting the old rounded topography. It was during this time

that the *Elephas* mentioned on p. 515 could have crossed from the American continent, since when there has been no connection.

(4) A depression to 100 feet or more below the present height, in mid-Tertiary days, and the accumulation of the Upper Petit-Bourg gravels and loams.

(5) A subsequent elevation to an altitude of 150 feet above the present, with the formation of short cañons along the coast.

(6) Again submergence to a little more than the present level with the growth of corals, as on the eastern coast.

(7) These reefs have been raised to a height of 6 or 8 feet. These latter oscillations of small amount may differ in the several islands, owing to local variations.

Remarkable as is the recurrence of so many changes in level, since the early Pliocene Period, yet the evidence is gathered from phenomena which also extend to the Greater Antilles and the American continent.

32. *On the* Geological *and* Physical Development *of* Anguilla, St. Martin, St. Bartholomew, *and* Sombrero. By Prof. Joseph William Winthrop Spencer, M.A., Ph.D., F.G.S. (Read April 24th, 1901.)

Contents.

I. Introduction.

The drowned plateau, standing boldly above the great submerged Antillean ridge, now forming the slightly sunken banks, out of which rise Anguilla, St. Martin, and St. Bartholomew, with some small outlying islands, is a repetition of the Antigua-Barbuda mass; in size a little larger, drowned a little deeper, more broken, and with its marginal declivities strikingly indented. Sombrero is an isolated feature.

Apart from the excellent contribution of Mr. P. T. Cleve,[1] there appears to be no geological account of the islands; but the discovery of mammalian remains by Edward Cope, among the bones obtained in Anguilla by Mr. Wager Ray, of that island[2] and the study of fossil echinoderms of the same island by Mr. R. J. Lechmere Guppy,[3] are important additions to our knowledge of the region.

II. Physical Characteristics.

The south-eastern extension of the St. Martin plateau, with its surface covered by only about 200 feet of water, is separated from the Antigua-Barbuda platform by a depression 18 miles across, but its depth beyond 858 feet has not been determined. The valley between the sunken tableland and Saba, to the south, is 20 miles wide and reaches a depth of 2934 feet; while that separating it, on the west, from Sombrero is scarcely wider, with the depth to the ridge crossing it reduced to 1800 feet. Beyond Sombrero is a channel of phenomenal depth, the only one of

[1] 'On the Geology of the N.E. West India Is.' Handl. k. Svensk. Vetensk. Akad. vol. ix, no. 12 (1870) pp. 1–48.

[2] First mentioned in a note in Proc. Acad. Nat. Sci. Philad. 1868, p. 313.

[3] 'On Tertiary Echinoderms from the West Indies' Quart. Journ. Geol. Soc. vol. xxii (1866) pp. 297–301.

its kind, dissecting the Antillean chain, entirely cutting off the sunken plateau of the Virgin Islands to the westward.[1]

The St. Martin plateau has a length of 75 miles and a maximum breadth of 45 miles, with an area of about 1800 square miles. The mountainous islands of St. Martin and St. Bartholomew rise as backbones of the sunken mass, while Anguilla and smaller islets represent the unsubmerged portions of the coastal plains, which latter are now generally covered with nearly 200 feet of water. Thus we have here a repetition of the topographical features of the Antigua-Barbuda mass.

Anguilla is 15 miles long, with Scrub Island, a disjointed extension of it. Its greatest breadth is 3 miles. The north-western side is characterized by cliffs, often vertical, as the waves are encroaching upon its shores. These cliffs are indented by several short cirques. They rise to an elevation of 150 feet, and at one point the summit reaches a height of 213 feet. The slightly undulating surface slopes down to the south-eastern shores, forming a peneplain.

In the centre is a broad depression, locally called The Valley, trending north-westward, but somewhat lower than its rim. The drainage being underground, there are no surface-streams over these limestone-plains, which are but thinly covered with soil. From a point midway along the coast, is an interrupted chain of islets and keys (called Seal Rocks) extending westward to Dog Island, and enclosing Crocus Bay. This is one of the most interesting features of the region, as it suddenly becomes a very deep amphitheatre at the head of a valley indenting the margin of the submarine plateau. From the col, at the head of Crocus Bay, another valley crosses the sunken banks in the opposite direction, extending to a deep embayment in the Atlantic side of the submarine plateau.

Dog Island (rising to a height of 80 feet) and Scrub Island (to 50 feet) are the most prominent outliers of the Anguilla group. The islets north of Crocus Bay are low, and partly covered with sand, while others are reefs, in part exposed to view upon the breaking of the surf.

St. Martin has a triangular shape, with diameters in each direction of 9 miles. The eastern two-thirds is compact in form, with its surface composed of narrow mountain-ridges or isolated points, separated by relatively large valleys. From the foot of the eastern side of the mountains, the surface slopes to form the remains of a base-level of erosion. The highest point has an altitude of 1360 feet, while others attain elevations of 1096 and 919 feet respectively. The mountainous part of the island is indented by bays, across the mouths of which the sea has cast up sand-beaches, as those of Flamand Bay and of Philipsburg, upon which the town is situated. Here the bay is used as a salt-pond, but borings in the underlying soil show that the silted-up valley is more than 60 feet deep. It

[1] See U.S. Hydrographic Charts Nos. 40 & 1002, or the corresponding British Admiralty Charts.

lies in the expansion of the mountain-valley as it nears the coast. The mountain-district is characterized by permanent streams, which become torrents with the tropical rains, during one of which I saw 8 inches of rainfall in 3 hours.

The western wing of the island is in part the remains of limestone-plains, but it is mostly composed of low flats out of which rise several ridges and hills (the remains of ancient features now connected by recent marine accumulations), the whole forming the border enclosing the island-studded waters of Simson's Inlet, a lagoon from 1 to 6 feet deep. The sunken shelf upon the eastern coast is narrow, and abruptly descends to a depth of 60 or 70 feet, while that on the southern coast soon becomes precipitous, as it is near the margin of the submarine plateau. Where the waves are not encroaching upon the shores, and the water is very shallow, coral-reefs are commonly found.

The northern part of St. Martin is separated from Anguilla by a depression 4 miles wide, with an uniform depth of 60 to 75 feet. This increases to the westward, where within a mile it descends precipitously 500 feet into the amphitheatre indenting the western margin of the sunken plateau. From this same depression, between the islands, another valley is traceable to the eastward. The question of the drowned valleys will be considered again under the heading of erosion-features (p. 530).

Tintamarre is a remnant of the coastal plain of St. Martin, though now separated from it by a channel 66 feet deep. It is a limestone-island like Anguilla, with a slightly undulating surface reaching to 90 feet above the sea. Its northern coast is being encroached upon by the waves, producing cliffs, while coral-reefs occur off the southern shores.

St. Bartholomew is a triangular island about 6 miles long, and is of the same general character as St. Martin. The northern shore sweeps round and encloses St. John's Bay, at the head of which the principal valley of the island is situated. It extends seaward, and becomes a deep bay between the main island and the chain of smaller ones to the northward. The western part of St. Bartholomew rises into a high ridge, while the eastern part is made up of isolated hills, the highest of which is 992 feet.

The distance between St. Bartholomew and St. Martin is 12 miles, with the intervening plain sunk from 80 to 100 feet, but there are several islets or rocks (one of which is 150 feet high) rising above the surface.

Sombrero is an isolated limestone-rock, 35 miles north-west of Anguilla. Its flat surface is about 25 feet above the sea, and it is everywhere bounded by precipitous cliffs, making the landing very dangerous owing to the prevailing swells in its exposed position. Occasionally the waves break over the whole island, which is less than a mile in length and 250 yards across. But the sunken bank out of which it rises has a length of 4 or 5 miles. Although it is separated from the eastern plateau by a deep depression 20 miles across, yet it is an outlier of it, as it is connected by a ridge which is not reduced to more than 1800 feet below sea-level, while the

main portion of the submarine platform is here sunk to a depth of 3000 feet or more. The great depth of the channel west of Sombrero entirely disjoins it from the Virgin-Island mass.

At the opposite or south-eastern extremity of the St. Martin plateau, separated from the rest of it by a deep channel, is a small, flat-topped, insular plateau now covered by about 200 feet of water. This is an interesting subject which will be considered under the head of erosion-features (p. 530).

III. The Older Geological Formations.

St. Martin is underlain by an old eruptive basement of greenstone or dioritic porphyry, in which crystals of triclinic felspar are prominent.[1] Where exposed at the surface, the rock is usually very much decayed, so that the best specimens of it are seen in the wave-rolled pebbles, where only the more compact material is found. The surface of the basement-rock may be seen along the southern shore, west of Philipsburg, where domes of it unconformably underlie the altered stratified beds above. The old igneous rocks occur at the surface along the road north of Philipsburg, which passes over a divide at 240 feet above the sea. It is here decomposed into a grey granular matrix, holding residual spherical masses of the less decayed material. Along the coast, south-east of Philipsburg, on the way to Point Blauche, is a light-coloured greenish mass of decomposed volcanic rock of a somewhat different appearance from the igneous basement-rock seen elsewhere. Mr. Cleve regarded it as a dyke, or intrusion, beneath the overlying formation. Whether a laccolite, or part of the older basement, it is very old.

The volcanic basement may be seen beneath some of the isolated ridges rising out of the flats which separate Simson's Inlet from the sea. Loose blocks of the same rock, occurring in the valley of Cul de Sac and elsewhere, have been derived from the central mountains, now mostly covered by another formation, or else by decayed material forming the soil which is creeping down the hillsides.

The overlying formation is complex, consisting of altered limestones, volcanic ashes, tuffs, and breccias, which have often been highly silicified or otherwise mineralized, presenting numerous variations. As this formation has been dislocated by endless faults, and the surface of the island has been subjected to excessive denudation, breaking it into disconnected ridges, the individual beds cannot be continuously traced. Accordingly, where the characters change, it is possible that I have included some tuffs and breccias belonging to the basement-series with the tuffs of the altered limestone-series. But whether this confusion has occurred or not, we find the series capping the mountain-ridges and also forming sea-cliffs

[1] I have not attempted petrographical accuracy, as the igneous rocks were not the primary object of the study. Mr. Cleve calls them 'syenite-porphyries,' the same as he found in St. Bartholomew; they are probably closely related to the old eruptives of Antigua.

along the southern and south-eastern coasts. The numerous faultings of the strata and the occurrence of dykes traversing the beds are common to all alike, irrespective of their character.

Beginning with Point Blanche, which is an isolated ridge from 500 to 600 feet above the sea, at the south-eastern extremity of the island, and separated from the main range by a deep valley, we find a thick formation of dark-grey siliceous limestones, mostly lying in nearly horizontal beds, though faulted. Along the side of the cove, at the eastern end of the ridge, the strata suddenly bend down so as to dip 40° north-westward, while at the other end of the ridge they locally dip and pass under the valley at nearly as great an angle in a south-westerly direction. Many of the beds occur in thin layers, but in some of the more massive the calcareous matter is intercalated with cherty layers, often only 1 to 4 inches apart. In some cases the silicification is complete. The whole series forms a very durable mass, and gives rise to strong topographic features. Some of the layers of these altered limestones are composed of volcanic ashes or tufaceous sands. The same rocks form the surface of the ridge, as well as the sea-cliffs, north of Point Blanche.

Along the southern coast, west of Philipsburg, a similar stratified formation constitutes the sea-cliffs. Generally its position is nearly horizontal, but very much faulted. It rests upon hummocks of the igneous basement-rock. The beds are mostly composed of chert, with intercalations of volcanic sand or tuff. But the cherty layers are often impure, from the admixture of the igneous débris. The calcareous matter here seems to have been more extensively replaced by the chert than at Point Blanche. Near Pelican Point some of the beds are rich in a manganese-oxide. Higher up the hillside the manganese-mines of Governor D. C. Van Romondt are located.[1] Here the strata are not separable from those nearer the shore, except that the mineralization is more complete, which gives them a different appearance. In the same layers the rich manganese-accumulations are liable to be replaced by the chert of a jaspery kind; in other beds oxides of iron occur.

It would thus seem that the mineralization and silicification are due to the alteration of the original impure calcareous beds. But even some of the interlaminated beds of volcanic débris are cemented by silica, producing a complex rock. Thus the heavier jasper-beds associated with the manganese-deposits east of the Philipsburg salt-ponds have a kaolinized white surface, from the decay of the felspathic impurities in the original limestone, or from the beds of chert in some cases being altered tufaceous deposits. On the upper Marigot Road the igneo-sedimentary rocks are well exposed to its summit (350 feet above sea-level). These strata are consolidated tuffs, penetrated by a dioritic dyke 1 foot wide.

Although no fossils have been found in these deposits, yet the conclusion arrived at places these beds, whether tufaceous, calcareous, or silicified, in one geological unit, consisting of a great

[1] The mineral is an impure psilomelane, containing a large percentage of manganese.

accumulation of volcanic tuffs and breccias, including beds of limestone, all of which have been more or less altered by the infiltration of siliceous waters, during the period of dislocation and secondary volcanic activity, when they were also penetrated by dykes. Any other explanation would place the formation out of harmony with the geological history of the area. This conclusion is supported by the investigation of Mr. Cleve[1] in St. Bartholomew, where he found, resting on the same kind of igneous basement, a great thickness of igneo-sedimentary strata, composed of breccias, conglomerates, and scoriaceous layers, varying in texture from fine-grained to coarse, in which latter case angular and rounded porphyritic fragments were commingled with finer material. The series contains intercalated beds of dark, very hard and compact limestone with cubical cleavage. The limestones are fossiliferous. Both these and the tuffs may be found silicified, but apparently to a less extent than in St. Martin. So too the limestones in St. Bartholomew seem to be more subordinate to the rest of the mass than in St. Martin. We have also seen that the old eruptive basement of Antigua is succeeded by a great accumulation of tuff, with intercalated beds of fossiliferous limestone which have been silicified. The recurrence of the same succession in the three neighbouring islands, in two of which their contained fossils show a common period of accumulation, suggests that the strata in St. Martin belong to the same age, a conclusion formed by Mr. Cleve so far as St. Bartholomew and St. Martin are concerned.

In St. Bartholomew, Mr. Cleve found numerous fossils, mostly in a poor state of preservation, among which the corals and foraminifera were abundant. These, if studied, would probably be more valuable in identifying the horizon than the molluscs, the poor preservation of which renders the specific determination difficult: of these he names a number of genera found in the limestones. He obtained two echinoderms—*Macropneustes* and *Echinolampas ovum-serpentis*, Guppy, the latter also occurring in the San Fernando Beds of Trinidad—and a decapod, *Ranina*. Among the molluscs was a species of *Argiope* and another of *Terebratula* (apparently *T. carneoides*, Guppy, also found in the Trinidad beds), a large *Nerita* (near *N. conoidea*, Lamk.), and also a large *Cerithium* (apparently *C. giganteum*, Lamk.), both of the Paris Eocene. From the palæontological evidence he concluded that the formation is the equivalent of the Middle Eocene of Europe. Thus the age of the tuff-limestone series in St. Bartholomew is shown to be practically the same as that of the tuff-limestone series in Antigua, or just below the beds which are there considered to be Oligocene, this being as close a correlation as the present data afford. Although the formation has been subject to greater variations and alterations in one locality than in another, the distribution in the neighbouring islands indicates that the same conditions prevailed throughout the area during the early Tertiary Period.

In Anguilla, underlying the limestones along the eastern side of

[1] Handl. k. Svenska Vetensk. Akad. vol. ix (1870) no. 12, p. 24.

Broad Bay, up to a height of 30 feet, are the decayed remains of igneous rocks in part resembling amygdaloids, and others are like volcanic ashes, all of a dark greenish or blackish colour. Volcanic rocks also underlie Dog Island. Thus there is an igneous foundation for all the islands from the western part of Antigua to Dog Island, the last of the chain, along the line, having a north-westerly direction. Beneath the cliffs, and rising scarcely above wave-action, between Road Bay and the landing to the east of it, there is a blue clay and also a gritty deposit containing lignite. These are probably the products of decomposition of the finer felspathic tuffs of the mixed series which occur in the other islands.

IV. The White or Antigua Limestones and their Fossils.

On the south-western flanks of the mountains of St. Martin, as, for example, near Pelican Point, the tuff-limestone series is unconformably overlain by a white limestone-formation. At this point the underlying beds dip 40° north-westward, while the overlying calcareous deposits dip about 15° south-westward. A short distance to the north-west, the same white limestone-formation overlies decayed igneous rocks, and caps the western side of an isolated ridge, while on the eastern side there is an escarpment 150 feet or more above Simson's Inlet. Here the beds dip slightly westward. The limestone in part is massive, while the bedding is not everywhere apparent. At Pelican Point it forms the surface of a plain, 75 feet above the sea. This is very much pitted, and the formation is characterized by numerous large caverns, one of which—Devil's Hole—appears to reach below sea-level. The surface of this rock is partly phosphatized, but no phosphate of lime was found in the shafts reaching to a depth of 75 feet, nor in a tunnel drifted in the side of a hill, showing that the phosphatic matter is confined to the surface. The subsequent physical movements are here shown in the slickensided walls, where the planes of slipping dip 75° westward.

The same limestones also occur a short distance away in the island of Anguilla, which was once evidently a part of the coastal plain extending from the mountains of St. Martin. Tintamarre, an adjacent outlier of St. Martin, represents a fragment of the dissected coastal plain. It is underlain by the same white limestones. While only a few undeterminable shells have been found in St. Martin, fossils occur in both Anguilla and Tintamarre; consequently these islands afford better localities for determining the age of the white calcareous formations.

Another limestone occurs at the eastern end of Point Blanche. It has a creamy colour, with a homogeneous texture, being really a hardened calcareous sand (locally called 'sandstone'), which is used for building purposes. It forms a cap 15 or 20 feet thick, unconformably above the silicified limestones, and dips at 35° south-westward. The surface is carved, by the action of the waves dashing upon it, into excellent miniature examples of the forms

of mountains and valleys produced by atmospheric erosion. No fossils are contained in these rocks, and their relationship is such as not to establish their age. From their texture and deformation it is suggested that they represent the lower beds of Tintamarre.

The sea-cliffs along the north-western shore of Anguilla afford opportunities for studying the limestone-formations. The direction of the coast-line often nearly coincides with the strike of the beds, which thus appear horizontal, when in fact they may dip at considerable angles into the island-mass. Between Road Bay and the landing to the east of it there is one section of brecciated limestones cemented by oxide of iron. These beds rise to a height of 30 or 40 feet; they contain fossils, but in a poor state of preservation. At other points, a marly limestone, interbedded with compact layers, rests upon a blue clay (scarcely above wave-action) and rises to a height of about 50 feet. This is succeeded by a more massive limestone from 40 to 50 feet thick, which causes the bluffs to retain their bold features. Overlying it is another marly deposit, of a yellowish colour, which has probably an equal thickness. The variability of the longitudinal exposures along the coast arises from extensive slippings of the higher strata (a fact which is often concealed) and from unconformity, as well as from the windings of the coast bringing to view different portions of the formations. In a cove north-east of the Crocus Bay landing, where the heavier limestone succeeds the marl, the strata dip 40° north-eastward (an exceptionally high disturbance). These are unconformably succeeded by another white limestone of compact texture, lying in horizontal beds. The two distinct formations, composed of the same materials, are not physically distinguishable where the unconformity is not apparent. Accordingly, fossils collected from beds whose relationship is not shown are likely to give rise to confusion of faunas. Fuller information may be derived from the corals and echinoderms, these being in a better state of preservation than the molluscs, which occur as casts.

Among the fossils previously obtained by Mr. Cleve, he mentions several genera of molluscs. He found *Natica phasianelloides*, d'Orb., a form widely distributed in the Miocene of the West Indies, *N. canrena*, Linn., and the tubes of a *Teredo* which occurs in Puerto Rico, as also several foraminifera. Mr. Guppy adds to the list of species found in other West Indian Miocene beds *Solarium quadriseriatum*, Sow., species of *Turritella* and *Pecten*, and teeth of a fish apparently closely allied to *Sphærodus gigas*; also eight species of echinoderms,[1] namely: *Echinolampas semiorbis*, Guppy, closely allied to *E. hemisphæricus*, Lam. of the Maltese and other Miocene localities; *E. lycopersicus*, Guppy, near *E. scutiformis*, Leske, of Malta and elsewhere; *Schizaster Scillæ*, Desmoulins, also found in Malta; *Echinoneus cyclostomus*, Leske and *Brissus dimidiatus*, Agassiz, both living species but rarely found fossil in

[1] Quart. Journ. Geol. Soc. vol. xxii (1866) pp. 297–301.

Anguilla; *Echinometra acufera*, Blainville, still living, but the fossil is of smaller size; *Cidaris melitensis*, Forbes, found in Anguilla; and *Clypeaster ellipticus*, Michelin, but the original locality was not known to Mr. Guppy. I found three of the species mentioned by him. From these resemblances to Miocene forms and the local types, and from the scarcity of the living species, occurring in only rare cases in the Anguilla beds, Mr. Guppy considers that these fossils add additional evidence of the Miocene age of the beds.

Among the corals which I obtained, a *Siderastræa* belongs to this general period, while two species—*Orbicella cavernosa*, Linn. and *Madrepora muricata*, Linn. var. *palmata*, Lam.—are living species, and evidently belong to the higher formation mentioned. These were kindly determined for me by Dr. T. Wayland Vaughan.

The evidence suggests that the Lower White Limestones of Anguilla belong to the Oligocene Period, and were deposited at the same time as the similar beds in Antigua. The upper strata, with a modern fauna similar to that of the Pointe à Pitre Usine limestones of Guadeloupe, are of later date, and were accumulated at a distance from the rocky shores of St. Martin, then reduced to small islands, about which the mechanical deposits of Point Blanche were being laid down.

Tintamarre is a small limestone-island covered with thin soil in the northern portion, while the surface, which slopes southward, is capped by a sandy deposit. The northern and north-eastern coasts are characterized by bluffs of white limestone and marl, in nearly horizontal strata similar to those of Antigua. In the upper part of these beds I obtained a few fossils, among which were two corals—*Orbicella cavernosa*, Linn. and *Diploria labyrinthiformis* Linn., both recent species. At the north-eastern end of the island is a cove showing cliffs rising to a height of 50 or 60 feet. Here the material is a light-coloured homogeneous marl, almost a calcareous sandstone, in which is included a thick layer of nodular limestone. The beds are sharply faulted, and upon their surface is a second nodular layer: they represent the lower calcareous beds of the island. The strata dip 20° south-eastward. On the surface of these fine-grained beds the only fossils observed were two species of echinoderms.

These last-mentioned beds appear to be the equivalent of the Lower Limestone of Anguilla, while those containing the recent species of corals, obtained in horizontal strata to the westward, represent the Upper Marls.

Sombrero is composed of marly white limestone rising to a height of 25 feet above the sea, with its superficial beds irregularly phosphatized. The pockets of this mineral having been extensively worked, its surface is much pitted, so that sections of both marly and more compact limestones are exposed in nearly horizontal strata. The overlying phosphatic rock having been removed, there are occasionally handsome colonies of coral exposed. Among those collected by me the most common forms belong to two

varieties of *Orbicella acropora*, Linn., a recent type. Several species of shells in the form of casts are common. Mr. Cleve identified *Tellina fausta*, Gold., *Cerithium litteratum*, Born, *C. caudatum*, Sow., *Fissurella Listeri*, d'Orb., and a *Bulla*—all except the last being living species, while the *Bulla* resembles *B. granosa*, Sow., a form occurring in Miocene beds of Santo Domingo; so that Mr. Cleve provisionally regarded the formation as late Miocene (which does not occur in the West Indies) or Pliocene. From the presence of recent corals, which are not found in the older Tertiary of Antigua, it seems that the deposit is no older than the close of the Pliocene, the same as the upper beds of Anguilla, Tintamarre, and the Usine Beds of Guadeloupe, yet antecedent to the epoch of stupendous erosion which left Sombrero a lonely sentinel, far out in the ocean, upon the edge of the now sunken Antillean ridge.

V. The Newer Formations.

A mantle of brecciated fragments of the Point-Blanche siliceous limestones covers a portion of the hillsides of south-eastern St. Martin. But where the Point-Blanche limestones have been removed by denudation, the mechanical deposit rests upon the surface of the decayed volcanic rocks. It is newer than the old White Limestones, which have been entirely removed from this locality; and as it has suffered such extensive denudation, I am inclined to correlate it with certain mantles in Antigua and Guadeloupe, which are provisionally regarded as belonging to the close of the Pliocene Period, and equivalent to the Lafayette formation of the American continent, in time about that of the deposition of the upper marls of Anguilla, Sombrero, etc., which were accumulated at a distance from the source of supply of such mechanical débris.

Another entirely distinct and more recent deposit is seen on the hill above Pelican Point, in the remains of a mantle of rounded waterworn gravel composed of igneous rocks, so recently waterworn and elevated that the surfaces of the pebbles are not yet decayed. The pebbles are mixed with the thin layers of rock-débris which are creeping down the hillside: they occur up to a height of 200 feet. On the north side of the divide, between Philipsburg and Oyster Pond, is almost a boulder-pavement at 190 feet above the sea. This was probably a residual or other accumulation left by the waves of the sea at the same time as the gravels seen on the hills.

Along the shore of Crocus Bay in Anguilla is a reddish sandy deposit overlying the limestones.[1] It is regarded as the equivalent of the waterworn St. Martin gravel. These loams and gravels are represented in the same geological position in the other islands,[2]

[1] At another point, overlying the upper marl is a mechanical deposit forming a thin mantle which may have been washed from the higher land.

[2] The Cassada-Garden Gravels of Antigua, the Lower Petit-Bourg loams and gravels of Guadeloupe, others of St. Kitts, etc.

and they are regarded as the equivalent of the Columbia formation of the American continent.

On the eastern coast of St. Martin, along the road near the residence of Mr. Wager Ray, the soil contains shells of living species. Similar deposits occur about Marigot, at a few feet above the sea. At another locality a terrace was observed at a height of 25 feet. Coral-reefs rise to the surface of the water off Anguilla and elsewhere.

VI. Mammalian Remains.

The caverns near Pelican Point contain cave-earth in which bones are found. In one, the earth has been partly removed, exposing 8 feet of red dirt, over which there are 9 inches of calcareous tufa, followed by 2½ feet of red earth, and covered by another 9 inches of tufa, the whole nearly filling the cavern, which is inhabited by bats. Numerous bones are said to have been taken out by the workmen. I saw the remains of (apparently) the radius of a mammal, but not in a condition for removal. It is possible that some of the bones, examined by E. D. Cope as coming from Anguilla, were obtained in this place.

In Anguilla, Mr. Wager Ray found a number of mammalian remains when digging for phosphate. I was fortunate in finding him on the island, and he kindly took me to the locality where he had obtained them—perhaps a mile north-east of the present landing, east of Road Bay. The cliffs are indented by sea-caves at a height of 60 feet, and many have become open fissures or cirques by atmospheric action. Their floors are covered by débris, which in some cases appear to have more or less filled them. In such a fissure the bones were obtained, among which Cope discovered remains of three species of *Amblyrhiza*—a rodent as large as a Virginia deer. Fragments of bones belonging to birds and other animals were also found. The importance of these remains will be referred to in connection with the question of changes of level of land and sea (p. 533).

VII. Erosion-Features.

The erosion-features of the now mostly sunken plateau of St. Martin are a repetition of those of the Antigua-Barbuda and Guadeloupe areas, but with local expressions of their own. St. Bartholomew and most of St. Martin are the remains of a mountain-district more severely denuded than the more south-easterly islands. The coastal plain, extending from the foot of the mountains, is seen in the western part of St. Martin, Anguilla, and some small islands, but it also includes the banks to the edge of the submarine platform, with its surface rarely drowned to more than 200 feet, while the unsubmerged points rise only to an elevation of about 200 feet, where they are found to be composed of the calcareous formation belonging to the early Miocene, the late Pliocene, or subsequent periods. The gently undulating

features are characteristic of denudation at the base-level of erosion, since modified by atmospheric and wave-action during the changes of level of the land. The broad valley-like depressions, extending from the precipitous slopes which bound the submarine plateau on all sides, except that on the Atlantic, to the neighbouring submerged tablelands, have also the features of base-levels of erosion, although they are now from 2000 to 2500 feet below the surface of the sea. As has been seen, the region, whether larger or not, was a land-area during the long Miocene-Pliocene Period. So also the degradation, during this time, not only carried away most of the White Limestone Series, but also removed the very durable siliceous limestones of St. Martin and formed great valleys which have so encroached upon the districts of each other as to reduce the mountain-ranges to isolated ranges separated by comparatively low divides, in which the evidence of differential erosion, in excess of that upon the hills, amounts to 500 feet or more of the hard siliceous limestones alone. Furthermore, there is no evidence of late local elevation of the St. Martin mass above the floor of the drowned Antillean chain, as in the mountainous part of Guadeloupe, where there has been an uplift, which was confined to the district of the more recent volcanic activity, but did not extend to the limestone-area of even that island. As the same phenomena occur in other islands, it can scarcely be doubted that the coastal plain extended to Antigua-Barbuda, St. Kitts (now mostly a mountain-range), the Saba Banks (a plain of 100 square miles in area, covered with 75 to 150 feet of water), and Sombrero. In this case, the phenomena indicate an elevation of 3000 feet above the present height, when the broad valleys between the drowned plateaux were being fashioned at the base-level of erosion, with the present submarine banks standing out as prominent tablelands at a period subsequent to the early Miocene emergence. With the subsequent sinking of the land later in the Miocene-Pliocene Period, the surface of the late tablelands was reduced to a low altitude, so as to permit of the atmospheric moulding of the surface of the (now mostly sunken) banks into forms characteristic of those of the base-level of erosion, with the margins of the mass modified by ocean-waves during the changes of level.

After the sinking of the area, subsequent to the existence of the extensive land-surfaces of the Miocene-Pliocene Period, when the undulating topography described was formed, a further subsidence carried it down to perhaps 200 feet below the present level, leaving only insignificant portions of the islands at about the close of the Pliocene Period, and giving rise to the accumulation of beds containing only a now living fauna.

Then followed the period of great elevation, having a duration very much shorter than that of the Miocene-Pliocene Period, with a tremendous amount of denudation, carving deep valleys out of the margin of the tableland. The excessive erosion was noted by Mr. Cleve in St. Bartholomew, where the surface is strewn with blocks and boulders. Vast quantities of boulders of decomposition

have been left upon the surface of St. Martin, on account of the finer materials of the decomposed igneous formation having been washed away. So also most of the mechanical deposits, supposed to have been accumulated during the subsidence at the close of the Pliocene Period, have been removed by the great amount of subsequent erosion. But the epoch of deep valley-making did not last sufficiently long for the complete dissection of the tablelands. One such, however, is seen at the south-eastern extension of the sunken platform, which is now from 150 to 200 feet below the sea-level, with a channel 2 or 3 miles wide extending across it and excavated to a depth of more than 1146 feet below sea-level; thus separating a small submarine plateau from the main mass—an illustration of how the drowned tablelands are detached. This is an actual development of the dissection of plateaus. But the valleys indenting the submarine plateau usually head in cirques or amphitheatres. Two conspicuous examples of these occur west of Anguilla, of much the same depth. One of them is a continuation of Crocus Bay. It extends 10 miles within the border of the mass where its surface-plains are covered by less than 100 feet of water, but the valley at its head is more than 680 feet deeper. The watercourses upon the summit of the tableland, and within its margin, were also somewhat deepened. Thus that at Philipsburg was deepened to the extent of 60 feet or more beneath the now silted-up basin forming the salt-ponds. The excavations, whose great depths, well within the borders of the submerged lands, extend to the broad valleys of the great Antillean plateau, which in this vicinity are sunk to 2500 or 3000 feet, consequently indicate that the land stood at such an altitude when they were formed. But the data for determining the additional height to which the now drowned Antillean plateau itself was raised are not obtained here. It was during this period of elevation that the caverns of St. Martin appear to have been excavated to below sea-level.

Sombrero, already left as an isolated promontory at the close of the Miocene-Pliocene Period, must have suffered an incalculable amount of destruction from its re-elevated summit precipitating the moisture from the trade-winds.

This epoch of great elevation was subsequent to the deposition of the marly beds containing the modern fauna, considered as occurring at the close of the Pliocene Period, and consequently after the Lafayette epoch of the American continent, or in the early Pleistocene Period.

The following subsidence of 200 feet below the present level, with the deposition of the St. Martin gravels and boulder-pavement, submerged Anguilla, and left only a few rock-ridges standing out in the ocean. This was a mid-Pleistocene feature, nearly contemporary with the depositions of the Cassada-Garden Gravels of Antigua, the Lower Petit-Bourg Series of Guadeloupe, or the Columbia formation of the American continent.

The subsequent elevation of the land to a height of 150 or 180

feet gave rise to a small amount of erosion, and the production of shallow channels which can be traced across the great banks. Then followed the sinking to a few feet below the present level, allowing the accumulation of the marine earths, since raised a little above the surface of the sea. Whether there is any terrestrial movement in progress now is not known.

VIII. Summary and Conclusions as to Changes of Level of Land and Sea.

(1) The St. Martin plateau was a land-surface throughout the long Miocene-Pliocene Period, during the earlier part of which it appears to have stood 2500 feet or more above the present level, and was probably connected with the now neighbouring insular masses, from which it was disconnected by denudation during a very long period of atmospheric activity, followed by subsidence, so as to bring the present surfaces of the submarine banks to a level so low that the undulating features of the base-level of erosion could be formed on them; for during the time when the deep and broad depressions on the Antillean chain were being fashioned, the now isolated island-groups stood out as table-mountains which were slowly being eaten away by atmospheric agents.

(2) A subsidence followed, of about 200 feet below the present level, with the accumulation of the Point-Blanche gravels, and the late limestones of Anguilla and Sombrero. Date about the close of the Pliocene Period.

(3) A re-elevation to 3000 feet as shown within the area, but in reality much more (as found outside of this restricted area). The epoch was characterized by the formation of great deep valleys excavated out of the margins of the highlands, but the time was not long enough for the recession of the gorges so as to dissect them completely. It was during this early part of the Pleistocene Period that the great rodents mentioned reached here from South America, as Cope found that they were allied to South American types of the Pleistocene Period, yet the race continued to live sufficiently long to give rise to distinct species. It seems to have survived until the region was again depressed and separated into islets, or submerged, when they were finally extinguished.

(4) The next submergence came in the mid-Pleistocene Period. It carried the land 200 feet below the present level, with the accumulation of the St. Martin gravels, etc.

(5) The subsequent elevation was marked by moderate denudation, with the production of shallow watercourses traceable across the sunken banks, to depths of 150 or 180 feet.

(6) Again there followed a moderate depression, so as to bring the surface to a few feet below the present level, succeeded by a rise of the low shell-bearing sands.

Numerous as these changes of level may seem, the same phenomena recur in the other islands, but the last minor movements vary in different localities.

33. *On the* Geological *and* Physical Development *of the* St. Christopher Chain *and* Saba Banks. By Prof. Joseph William Winthrop Spencer, M.A., Ph.D., F.G.S. (Read April 24th, 1901.)

Contents.

I. Introduction.

The islands of Saba, St. Eustatius, St. Christopher, Nevis, Redonda, and Montserrat form the interrupted extension of the mountain-district of Guadeloupe, constituting a succession of volcanic ridges, surmounting the Caribbean side of the eruptive belt, which is seen to have a breadth, at sea-level, of 35 miles.

The Saba Banks, situated upon the south-western side of the eruptive backbone of the Antillean chain, correspond to the sunken areas of the St. Martin-Anguilla and Antigua-Barbuda banks, upon the eastern side.

William Maclure's contributions in the early part of the nineteenth century refer to some of these islands.[1] Mr. P. T. Cleve's paper[2] is, however, the most valuable geological publication on the subject. Locally, Dr. Christian Branch and his father have given much attention to the natural history of St. Kitts, and they kindly conducted me to many points of interest.

II. Physical Characteristics.

St. Christopher, everywhere in the West Indies called St. Kitts, with St. Eustatius, called Statia, on one side, and Nevis on the other, form a trisected ridge, fringed by a narrow submarine coastal plain, sunk to a depth of between 80 and 140 feet, which last rises above the floor of the submarine Antillean plateau to a height of between 2000 and 2700 feet or more. Saba is an isolated volcanic cone rising out of equally deep water; and Montserrat, to the

[1] Journ. Acad. Nat. Sci. Philad. vol. i, pt. 1 (1817) p. 134.

[2] 'On the Geology of the N.E. West India Is.' Handl. k. Svensk. Vetensk. Akad. vol. ix (1870) no. 12. An abstract of this paper appeared in Ann. N. Y. Acad. Sci. vol. ii (1881) pp. 185-92.

south-east, is another island of more varying character along the same axis. This submarine chain, which is about 100 miles long, does not exceed a breadth of 10 miles, including the fringe. The depression between Nevis and St. Kitts has a depth of less than 30 feet, with a rugged bottom; while the shelf between St. Kitts and Statia is a somewhat undulating plain, commonly covered by 100 to 180 feet of water. The St. Kitts ridge is separated from Montserrat by a depression reaching to a depth of 2000 feet, out of which rise Redonda, an isolated volcanic rock having a height of 600 feet, and an adjacent bank. But this depression is traversed by a channel 600 feet deeper (2592 feet). From the Statia end of the St. Kitts range to the Saba Banks, the connecting ridge is probably sunk not more than 1200 feet, but it is indented by an embayment trending northward, which reaches down to more than double this amount, so that, in a direct line between Statia and Saba, the sea attains a depth of 2748 feet.

St. Kitts, 19 miles long, is principally a volcanic ridge, surmounted by several peaks, the highest of which is Mount Misery, rising to an elevation of 4319 feet. The lip of the crater is 700 feet lower, and, according to Dr. Christian Branch, the bowl has a further depth of 700 feet, with a diameter of a quarter of a mile, which is occupied in wet seasons by a lake. But the south-eastern extension of St. Kitts, almost separated from the main part of the island, forms the remnant of older igneous formations, which have not been buried by the volcanic eruptions of later date. The mountain-ridge of St. Kitts is bordered by gently-sloping surfaces or glacis covered with volcanic soil.

Nevis, nearly circular, with a diameter of 7 or 8 miles, is similar to the main part of St. Kitts, but it is composed primarily of one volcano, rising to 3596 feet above the sea, with some adventitious prominences.

Statia, an island with a length of about 5 miles, is characterized in its northern part by denuded ridges of old igneous rocks, the highest point of which is 960 feet. The central portion is a peneplain, or remnant of an old land-surface; while the southern portion is surmounted by a crater, called 'The Quill,' which reaches a height of 1950 feet.

Saba is an isolated peak, 2820 feet high, with no other crater (according to Mr. Cleve) than the circular space, from 700 to 1000 feet above the sea, now occupied by the town of 'Bottom.'

The Saba Banks constitute a large remnant of the coastal plain upon the Caribbean side of the mountain-chain just described. They have a length of about 35 miles and a breadth of 20 to 25 miles, making an area of about 800 square miles. These banks form a submerged tableland rising 3000 feet or more above the floor of the Antillean plateau. Its surface, traversed by shallow channels, is covered by only 80 to 150 feet of water.

III. The Volcanic Formations.

The remnants of the old igneous foundation are seen in the denuded hills and valleys of the 'Salt Ponds' district, or the south-eastern extension of St. Kitts. The topographic features resemble those of St. Martin and the mountain-district of Antigua. Similar features are seen in the northern part of Statia. Everywhere else these beds are covered by the much more recent volcanic formations. The newer materials are mostly incoherent volcanic ashes or cinders, much decomposed, with small angular pebbles and occasional boulders of trachytic character, containing crystals of triclinic felspar, liable to become white from kaolinization, and some hornblende. At some of the higher altitudes the beds of tuff are more coherent. At all the lower elevations the surface of the island is covered by re-washes of loose material. The stratification of the deposit dips outward. At one place only were lavas seen, namely, at a point on the northern shore, 11 miles from Basse Terre, where a sheet of black basalt occurs at a height of 25 feet above the sea, covered with marine sandy tuff showing signs of wave-action. Dr. Christian Branch states that no other lava-deposits are exposed on the island, except perhaps some 'black rock' reported at points difficult of access among the mountains. The character of the igneous rocks has not been made a subject of special study by me, as the volcanic phenomena were not the primary object of my visit to the islands; but their relationship to the other formations is an important question. No eruption is recorded as having occurred during the historic period upon any of these islands, although they are still visited by severe earthquake-shocks. The ridges, which are being rapidly dissected by the enormous precipitations of moisture from the trade-winds, are still more or less intact. The tuffs also extend under the marine deposits forming the present floor of the sea, as shown at Brimstone Hill, where these have been thrust upward by a local volcanic upthrust, which is independent of the general changes of level that have affected this area.

IV. The Limestones of Brimstone Hill.

Brimstone Hill is a secondary and adventitious volcanic dome, having a diameter at the base of about half a mile, and its summit reaches a height of 700 feet. It is composed of loose or semi-coherent tuffs, the beds showing intense contortion and fracture. It is covered by a mantle of white marl or limestone, from 15 to 30 feet thick, much fractured and dipping everywhere outward from the central dome, even at angles approaching the vertical. The mantle occurs only to a height of 450 feet. This feature is repeated at the southern end of Statia, 12 miles away, where the limestone-mantle has been carried up to a height of 900 feet, upon the flanks of the crater-cone, which rises to an altitude of 1950 feet, and is still well preserved, although composed only of cinders. But the volcanic activity which produced Brimstone Hill does not appear to

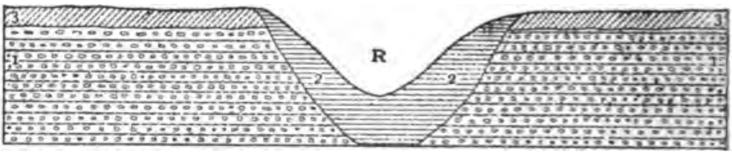
have been accompanied by an eruption. Owing to these two volcanic uplifts, the limestones which underlie the submerged coastal plains may be seen, for they appear nowhere else on these islands. These deposits are composed of white marls, of soft earthy texture, but compact in places. The surfaces are case-hardened from exposure to the weather. Fossils are abundant at certain points, but the shells are mostly in the form of casts, although some are better preserved in the volcanic sands (these are also calcareous) which immediately underlie the marls. The echinoids are in a better state of preservation, as are also the corals, which Dr. T. Wayland Vaughan kindly determined for me:—*Orbicella cavernosa*, Linn., *O. acropora*, Linn., *Siderastræa siderea*, Ell. & Sol., all of which are living species. *Orbicella acropora* is the most common form on the island of Sombrero. The shells were also kindly determined for me by Mr. Charles T. Simpson:—*Venus cancellata*, Linn., *V. Paphia*, Linn., *Cardium sublongatum*, Sow., *Glycimeris pectinatus*, *Gl. undatus*, Lam., *Lutricola interstriata*, Say, *Tellina interrupta*, Wood, and *Pecten ziczac*, Linn.? These are all living species. Mr. Cleve seems to have found a still larger number of species, and among them a *Modiola*, not living in the Caribbean Sea, though closely related to a species existing in northern waters. He also obtained *Tellina Gruneri*, Phil., a shell rarely found in the adjacent seas, but occurring in the Miocene strata of Cuba and Puerto Rico; consequently he was disposed to regard the formation as newer Pliocene or Pleistocene. From the evidence, the deposit cannot be older, but the fossils do not tell us to which epoch, since the later days of the Pliocene Period, they belong; it is necessary therefore to base this determination upon physical resemblances and the general succession of events in the whole region. The formation appears to correspond to the surface-marls of Sombrero, the upper marls of Anguilla, and those at the Usine of Pointe à Pitre in Guadeloupe. These have about the same thickness, contain a similar fauna, and are regarded as the equivalent of the Lafayette formation of the American continent, belonging to the time about the close of the Pliocene Period. Their drowned surfaces present erosion-features of considerable age, which will be considered again (p. 540). The elevation of the volcanic domes of Brimstone Hill and The Quill are of a very much later date.

V. The St. Kitts Gravels.

While the surface of the island is covered with washes of volcanic débris, there are some sections along the coast having a height of 50 feet. Between Basse Terre and Old Road, for a distance of about a mile, the strata are seen to be composed of rounded gravels, some pebbles having a diameter of 4 to 8 inches, intermingled with more or less angular material, which had been carried into the sea by the rain-washes during the accumulation of the gravels. This gravel-formation is seen to be dissected, as shown in the accompanying figure (p. 538), by a ravine about 100 feet wide, which

was subsequently refilled by marine beds of sand. All these strata appear horizontal. The situation of the gravel-beds is such as would favour the accumulation of coarse materials at this point, while finer materials would be deposited at other localities. Overlying the lava-beds on the northern side of the island, and also 2 miles south-eastward, at the mouth of a valley, are beds of horizontally stratified volcanic sand well exposed to a height of 50 feet. From their extensive development and position, they are evidently of the same age as the coarser gravels near Old Road. The coarse gravels of this latter-named locality give form to a sloping plain which rises to a height of 200 feet, suggesting that the gravels occur up to this elevation, though covered by land-washes. In a ravine upon the flanks of Monkey Hill, behind Basse Terre, to which I was taken by Dr. Branch, there had been exposed a shell-bearing bed, where he had collected several marine shells of still living species. This was at an altitude of about 300 feet. Mr. Cleve also recorded the occurrence of this or a similar bed. Their connection with the coastal sections was not made out,

Section of the St. Kitts Gravels (1) *dissected by a ravine* (R), *refilled with stratified sand* (2) *and since partly re-opened. Gravels covered with surface-wash* (3).



but it is most reasonable to suppose that the subsidence, which permitted of the accumulation of the gravels, was that which allowed of the deposition of the shell-beds found by Dr. Branch and Mr. Cleve, in which case the subsidence reached a depth of 300 feet.

From the above section near Old Road, it is seen that the gravel-beds were lifted above the sea-level and denuded, with the production of moderate-sized ravines, thus marking a different epoch of change of level, followed by another subsidence to a depth of 40 or 50 feet, and the refilling of the little ravine. The whole has since been re-elevated.

These gravels and volcanic sands occupy the same position in the succession of the West Indian deposits as the Upper Petit-Bourg Series of Guadeloupe, the Cassada-Garden Gravels of Antigua, or the gravels of St. Martin, which are provisionally correlated with the Columbia or mid-Pleistocene formation of the American continent; while the fillings of the small valleys dissecting them are the accumulations of a short interval of later date, represented by the low-lying shelly beds of St. Martin, Antigua, and Guadeloupe.

VI. Date of the Volcanic Eruptions.

We are now in a position to consider the volcanic accumulations in relation to the marine deposits which overlie them. Some of the volcanic sands underlie the marls which thinly cover the floor of the sunken coastal plains, as seen in the limestones of Brimstone Hill and The Quill; consequently, the renewal of Tertiary igneous action commenced before the formation of the marls, the sands beneath which contain the remains of recent shells. There are no deep valleys dissecting the volcanic deposits of the islands, such as appear indenting the submarine shelves, portions of which, at least, are covered with these marls; so that the cinder-eruptions must have renewed the surfaces of the islands, and largely built up the volcanic ridges since the marl-producing epoch. Again, the mountain-ridges were completed nearly as we now see them, before the elevation of the adventitious dome of Brimstone Hill, which dates back only to the period of submergence recorded in the gravel-formations of the mid-Pleistocene Period. Consequently, the greatest volcanic activity appears to have been during the earlier part of the Pleistocene Period, which was particularly characterized by stupendous changes of level of land and sea, although these began somewhat earlier. From the freshness of the mountain-slopes, the eruptions seem to have recurred nearly to the present day. This newness is impressed upon us, when we see the destruction wrought by the rains, precipitated by the mountains from the trade-winds. Clouds hang over, if they do not envelop, Nevis and Mount Misery for most of the year. During a storm lasting three hours, in 1880, there was a local condensation, so that a rain-gauge of 30 inches at Basse Terre was filled and overflowed (*teste* Dr. Branch). The terribly destructive effect of such a rainfall is understood, even without adding that the slackened currents deposited in the town from 4 to 6 feet of mud. Yet outside of the influences of the mountains, the rainfall, even in this tropical region, is very moderate, as in Antigua and Anguilla.

While corals grow upon the coast and obstruct some of the channels on this submarine shelf, they are not found in reefs elevated above the sea.

VII. Notes on Redonda and Montserrat.

Sailing from Nevis to Montserrat, one passes the lonely rock of Redonda, rising to a height of 600 feet, which has so far defied the stress of storms and waves. A phosphate-deposit has been worked upon its surface, but I am unaware of its geological relationship, not having landed on the island.

Nor have I seen Montserrat, except from the deck of a steamer. Yet it is made up of volcanic peaks similar to others of the chain, the highest attaining an elevation of 3002 feet. Remnants of a limestone occur at a headland, and specimens were shown to me by

Mr. Watt, of Antigua. It resembles the White Limestones of the other island. Among the collections sent by Nugent to London, Duncan[1] found the coral *Astræa Antillarum* closely allied to *A. endotheca*, which is an old Miocene type occurring in Antigua and Santo Domingo. Thus in Montserrat, there is a fragment of the same geological foundation, of the recent topographical features, as in other adjacent islands.

VIII. Erosion-Features.

The sunken tableland now forming the Saba Banks and the chain of islands from Saba to Montserrat, rises above the floor of the submarine Antillean plateau to a height of 2000 feet or more, in the same manner as the other groups of the north-eastern Antilles, which are regarded as the remains of a vast tableland dissected in the earlier part of the Miocene-Pliocene Period. But the information derived from erosion-phenomena upon the surface of these islands is of the most fragmentary character, as the vast Saba plain and the corresponding foundation of the volcanic islands have been either submerged or covered by more recent ejectamenta, leaving only the limited, central, base-level peneplains and the northern hills of Statia, the south-eastern hilly part of St. Kitts, and fragments of Montserrat, comparable with the mountain-districts of Antigua and St. Martin. Consequently, we are left to consider only topographical outlines more recent than the Miocene-Pliocene Period; and so far as the surface is concerned, more recent than even the period of great elevation of the early Pleistocene Period, which was characterized by very deep valleys, dissecting the more rounded outlines of the earlier topography. However, upon the submerged margins of the area under consideration occur some interesting erosion-features. Thus there is an embayment indenting the sunken ridge between Saba and Statia, reaching to a depth of more than 2562 feet, while the adjacent part of the sea-floor is only about 1200 feet below the surface.[2] The channel over 2000 feet deep, between Saba and Saba Banks, is not probably due to erosion, but to the elevation of the volcanic cone at the foot of the tableland now submerged. The channel, reaching to a depth of 2592 feet, between Nevis and Redonda, dissects the sea-floor (which here generally reaches to about 1800 feet), and is a repetition of the valley-feature just mentioned. The margins of the Saba Banks are also indented by cirques. The shelf, north-east of Statia, submerged to less than 150 feet, which is apparently covered with a limestone-floor like that shown at Brimstone Hill and in Statia, is indented by an amphitheatre having a depth of more than 1476 feet. This phenomenon suggests that the epoch

[1] 'On the Fossil Corals of the West Indian Is.' Quart. Journ. Geol. Soc. vol. xix (1863) p. 452, and following papers.

[2] See U.S. Hydrographic Chart No. 40, or the corresponding British Admiralty Chart, and also a chart on a still larger scale.

of deep excavations into the borders of the highlands was subsequent to the formation of the marl-beds, which are supposed to belong to the close of the Pliocene Period. Although the data for studying these deep valleys are more fragmentary here than among some of the neighbouring groups of islands, yet they are found to have the same characteristics. The surfaces of the shelves between Statia and St. Kitts, and again south of Nevis, have the undulating features of erosion of elevated plains inside the margins bounding their slopes, and indicate that the volcanic ridges, upon the St. Kitts chain of islands, were largely built over an old erosion-surface and plains like the Saba Banks. Furthermore, it appears that the growth of the volcanic mountains is one of recent date, without the igneous disturbances extending beyond the limits of the ridges themselves.

Subsequent to the production of the erosion-features just described as characterizing the early Pleistocene Period, the next evidence bearing on the geological history is seen in the ravines of small size which dissect the gravels near Old Road, consequently a late Pleistocene feature. The fringing-banks about the islands are also somewhat channelled, to 60 or 75 feet below the surface, showing that the land was at least that amount higher when they were formed than now. By this elevation Nevis was connected with St. Kitts for the last time, since when a considerable time must have elapsed, sufficiently long for some changes in the land-molluscs to have been effected. In this connection Dr. Branch informs me that a larger species of *Dentularia* (a subgenus of *Helix*), and *Bulimus elongatus*, Pff. (belonging to a subgenus of *Helix*), are no longer living in St. Kitts, although abundantly found there as sub-fossils, while the species, in a degenerate form, survive in Nevis. The ravines, excavated out of the gravel-formation and now refilled by a newer deposit to a depth of 40 or 50 feet, show the subsequent sinking of the land to this amount, followed by a re-elevation. These changes of level have their counterpart in the neighbouring islands. All other erosion-features of the islands are only such as are in progress at the present day.

IX. Summary and Conclusions as to Changes of Level of Land and Sea.

The Saba Banks and the foundations of the adjacent islands rise above the floor of the submarine Antillean plateau as tablelands, with their margins indented by embayments, similar to the banks of the St. Martin and Antigua groups, and so it is inferred that the area underwent the same physical history:—namely, tablelands rising to 2000 feet or more, during the earlier Miocene-Pliocene Period; followed by a partial sinking that prevented the complete dissection of the region, and left the Saba Banks and the foundation-plains of the volcanic islands (on one of which there is a fragment of

the old Oligocene limestone still remaining) as land-surfaces during the greater part of this long era. The subsidence of the land being renewed, its surface was covered by a mantle, from 15 to 30 feet in thickness, of marly limestones, containing shells of living species, but not until after the late Tertiary volcanic activity had commenced. These phenomena would not have been seen, had not Brimstone Hill and The Quill been subsequently thrust up by local eruptions of a still later date. While the fossils do not indicate to which recent epoch they belong, their considerable age is shown in the erosion-features of the surface of the banks, and their margins, which are indented by the very deep valleys described. These marls are regarded as of the same age as the upper marls of Anguilla, of Sombrero, of Guadeloupe, etc., which are correlated with the Lafayette formation of the American continent, or belonging to about the commencement of the Pleistocene Period.

This epoch of subsidence was followed by that of the somewhat long and stupendous elevation and erosion of the region, when the deep valleys and *cirques*, indenting the margins of the tablelands, and the relatively broad but shallow channels upon their surfaces, cut back from their edges, were produced by atmospheric agents during the early part of the Pleistocene Period. From the local evidence, the elevation does not appear to have been more than about 3000 feet above the present surface. But it should be noted that a vastly greater altitude is indicated beyond this area.[1] The great mass of the volcanic ridges seems to have been built up or elevated during this long epoch, and largely completed before the next epoch, which was one of subsidence.

This depression does not seem to have exceeded 300 feet below the present level, when the gravels, sands, and deposits containing living species of shells, now found at this height, were accumulated. These gravels and sands occupy the same position as those of Cassada Garden in Antigua, the Upper Petit-Bourg Series of Guadeloupe, and the gravels of St. Martin, all of which are correlated with the Columbia formation of the American continent, which belongs to the mid-Pleistocene Period. It was during this epoch of subsidence that the domes of Brimstone Hill and The Quill of Statia appear to have been formed. The succeeding upward movement carried the land to 60 feet or more above its present height; then the ravines, now buried, and the small channels in the sunken shelf were excavated. Again the land was slightly depressed, to 40 or 50 feet, and the ravines just referred to were refilled. There is a corresponding formation in the other islands.

The re-elevation which raised these sediments to the height of 40 or 50 feet, is the last change noted, but as the coral-reefs along the coast are not elevated, it is possible that a downward movement is in progress.

All the oscillations of level are recorded in the adjacent islands,

[1] See 'Reconstruction of the Antillean Continent' by the present writer, Bull. Geol. Soc. Am. vol. vi (1895) pp. 103–40.

but the amounts vary somewhat in the different groups of islands, as also the character of the evidence. Thus, in this group, the floor of the sunken plains was nowhere seen lifted to the surface by the general changes of level, as in other islands. The elevation of the area, so far as can be discovered, is in no way dependent upon the volcanic forces outside of the districts occupied by such ridges. The various groups of islands, now partly drowned, so as to constitute the banks, are the surfaces of tablelands, in part surmounted by mountains, which rise conspicuously above the floor of the Antillean plateau. They were not raised into prominence by eruptive forces beyond the limits of the volcanic ridges themselves. On the other hand, the slopes or escarpments bounding them are everywhere marked by excavations, indicating the intense atmospheric erosion to which they were long subjected.

Discussion (on the four preceding Papers).

Prof. Hull having expressed his thanks to Prof. Watts for the able manner in which he had prepared the printed abstracts of the papers, and, in the absence of the Author, communicated their contents to the meeting, said it would be evident that the Fellows had before them the results of great labour, extending over several years, and following up the results communicated to the world in the remarkable memoir on 'The Reconstruction of the Antillean Continent.' The results of the Author's investigations in all the islands described were in general agreement with each other—showing that the islands themselves were but the higher unsubmerged summits of a continental plateau which once extended, during a period of high elevation, from South to North America, and had undergone several oscillations of level, the most important being the elevatory movement at the close of the Pliocene Period, amounting to over 3000 feet, which gave opportunity for the migration of *Elephas* from the continent to the Island of Guadeloupe, and for the large rodents (described by Cope) to enter the region now constituting the Island of St. Martin. It seemed to him that this great elevatory movement, evidenced by the existence of the submerged river-channels, had its counterpart along the eastern borders of the Atlantic, as shown by the submerged river-channels of the British Isles, Western Europe, and the Congo. In conclusion, he desired to join in thanking the Author for his communication to the Society.

Prof. Sollas, in commenting on the four papers of the Author, which were really one, and might conveniently be collected together as dealing with the geology of the Windward Isles, remarked that, with regard to the great submergence imagined by the Author, it appeared to rest on an argument of the following nature: all valleys owe their existence to the excavating power of rivers; the submarine troughs of the Antilles are valleys, and consequently were produced by rivers. It was difficult to give unconditional assent to either of these premisses; although many valleys have undoubtedly been

modelled by river-action, yet in many cases the fundamental outline has resulted from orogenic movements. That great movements of the earth's crust have occurred in the Antilles may be proved by a variety of evidence. The sections through the submarine troughs of the Antilles exhibited before the Society did not recall the familiar form of river-valleys, but rather suggested fault-troughs crossed by step-faults. The Author might possibly be correct in his contention; but until additional evidence was forthcoming, the supposed great submergence could not be regarded as a fact placed beyond doubt.

Mr. R. S. Herries drew attention to the very fine exhibition of West Indian fossils and other specimens from the Society's Museum. He thought the Fellows present would see for themselves that the specimens were clean and well kept; and he hoped that this display would go far to prove that the Council and officials of the Society were not quite so careless of their trust as had recently been represented.

GENERAL INDEX

TO

THE QUARTERLY JOURNAL

AND

PROCEEDINGS OF THE GEOLOGICAL SOCIETY.

END OF VOL. LVII.

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

PROCEEDINGS

OF THE

GEOLOGICAL SOCIETY OF LONDON.

SESSION 1900–1901.

November 7th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Additional Notes on the Drifts of the Baltic Coast of Germany.' By Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S., and the Rev. Edwin Hill, M.A., F.G.S.

2. 'On certain Altered Rocks from near Bastogne, and their Relations to others in the District.' By Catherine A. Raisin, D.Sc. (Communicated by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.)

The following specimens and maps were exhibited:—

Rock-specimens and Microscope-sections, exhibited in illustration of Miss C. A. Raisin's paper by Prof. T. G. Bonney, D.Sc., LL.D., F.R.S., F.G.S.

Palæolithic Implement found at Minster (Thanet), exhibited by George Clinch, Esq., F.G.S.

Geological Survey of England & Wales: 1-inch Geological Map, n. s., Sheet 232 (Solid & Drift) and Sheet 316 (Drift). Geological Survey of Ireland: 1-inch Geological Map (new editions), Sheets 47, 80, & 88. Presented by the Director-General of H.M. Geological Survey.

United States Geological Survey: Geologic Atlas, Folios 38–58. Presented by the Director of that Survey.

November 21st, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

John Norton Griffiths, Esq., Rhodesian Mining Co., 3 & 4 Great Winchester Street, E.C.; James Parsons, Esq., B.Sc., 6 Hillside, Cotham, Bristol; Frederick Ross Thomson, Esq., Hensill, Hawkhurst (Kent); Hubert Tylden-Wright, Esq., Coalfields, Dundee (Natal), and Mapperley Hall, Nottingham; and Arthur Vaughan, Esq., 9 Pembroke Vale, Clifton, Bristol, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'A Monchiquite from Mount Girnar, Junagarh (Kathiawar).' By John William Evans, D.Sc., LL.B., F.G.S.

2. 'The Geology of Mynydd-y-Garn (Anglesey).' By Charles A. Matley, Esq., B.Sc., F.G.S.

3. 'On some Altered Tufaceous Rhyolitic Rocks from Dufton Pike (Westmorland).' By Frank Rutley, Esq., F.G.S. With Analyses by Philip Holland, Esq., F.I.C., F.C.S.

The following specimens and photographs were exhibited:—

Rock-specimens, Microscope-sections, and Lantern-slides, exhibited by Dr. J. W. Evans, LL.B., F.G.S., in illustration of his paper.

Rock-specimens and Microscope-sections, exhibited by C. A. Matley, Esq., B.Sc., F.G.S., in illustration of his paper.

Rock-specimens, Microscope-sections, and Lantern-slides, exhibited by F. Rutley, Esq., F.G.S., in illustration of his paper.

Photographs of Buddhist Temples, excavated in Æolian Limestone, and showing False-Bedding in the Rocks, Junagarh (Kathiawar), exhibited by Dr. J. W. Evans, LL.B., F.G.S.

Thirty-three Photographs illustrating South-African Geology, by E. H. L. Schwarz, Esq. (of the Geological Survey of Cape Colony), exhibited by Prof. J. W. Judd, C.B., LL.D., F.R.S., F.G.S.

December 5th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

H. N. Bowden-Smith, Esq., B.A., Careys', Brockenhurst (Hants), and Trinity College, Oxford; the Rev. John Bufton, Bunbury (Western Australia); Hervic Nugent Grahame Cobbe, Esq., Burbank,

Grand Junction Ltd., Coolgardie (Western Australia); John R. Don, Esq., Head Master of Waitaki High School, Oamaru, Dunedin (New Zealand); Robert Hugh Geoghegan, Esq., B.A., King's College, Cambridge; James Edward Gomersall, Esq., St. Andrew's Terrace, Batley; George E. Harris, Esq., Margherita, Upper Assam (India); Gordon William Harris, Esq., Assoc.M.Inst.C.E., 133 Lewisham Road, London, S.E.; Henry Hubert Hayden, Esq., B.A., B.E., care of Messrs. Grindlay & Co., 54 Parliament Street, S.W.; Primrose McConnell, Esq., B.Sc., Ongarpark Hall, Ongar (Essex); William McPherson, Esq., 2 Manilla Road, Clifton, Bristol; Charles Stewart Middlemiss, Esq., Superintendent, Geological Survey of India, care of Messrs. Grindlay & Co., 54 Parliament Street, S.W.; Fortescue William Millett, Esq., Marazion (Cornwall); Alexander Montgomery, Esq., M.A., Manukan Road, Parnell, Auckland (New Zealand); Herbert Brantwood Muff, Esq., Aston Mount, Heaton, Bradford; Lieut. Francis Hungerford Pollen, Farley, Reigate (Surrey); William Poole, Esq., B.E., 87 Pitt Street, Redfern, Sydney (New South Wales); the Rev. Granville H. Ramage, 9 Comely Bank Road, Walthamstow, E.; Linsdall Richardson, Esq., 10 Oxford Parade, Cheltenham; Bernard William Ritso, Esq., Assoc.M.Inst.C.E., Public Works Department, Cape Town; William Young Veitch, Esq., L.R.C.P.Edin., The Crescent, Middlesbrough (Yorkshire); and Henry James Weaver, Esq., Borough Engineer & Surveyor, Town Hall, King's Lynn, were elected Fellows of the Society.

The List of Donations to the Library was read.

The President announced that Mrs. Hicks had presented to the Society a framed Photographic Portrait of the late Dr. Henry Hicks, F.R.S. (Secretary from 1890 to 1893, President from 1896 to 1898.)

The following communications were read:—

1. 'On the Corallian Rocks of St. Ives (Huntingdonshire) and Elsworth.' By Charles B. Wedd, Esq., B.A., F.G.S. (Communicated by permission of the Director-General of H.M. Geological Survey.)

2. 'The Unconformity in the Coal Measures of the Shropshire Coalfields.' By William James Clarke, Esq. (Communicated by W. Shone, Esq., F.G.S.)

3. 'Bajocian and Contiguous Deposits in the North Cotteswolds: the Main Hill-Mass.' By S. S. Buckman, Esq., F.G.S.

The following specimens were exhibited:—

Specimens exhibited by C. B. Wedd, Esq., B.A., F.G.S., in illustration of his paper.

Specimens exhibited by S. S. Buckman, Esq., F.G.S., in illustration of his paper.

Pebbles from the Stonesfield Slate of Stonesfield, exhibited by Prof. H. G. Seeley, F.R.S., F.L.S., V.P.G.S.

December 19th, 1900.

J. J. H. Teall, Esq., M.A., F.R.S., President, in the Chair.

David Forbes, Esq., 3 Aytoun Road, Brixton, S.W., was elected a Fellow; M. Gustave F. Dollfus, of Paris, was elected a Foreign Member; and Prof. Ernst Koken, of Tübingen, a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Igneous Rocks associated with the Cambrian Beds of the Malvern Hills.' By Prof. T. T. Groom, M.A., D.Sc., F.G.S.

2. 'On the Upper Greensand and Chloritic Marl of Mere and Maiden Bradley in Wiltshire.' By A. J. Jukes-Browne, Esq., B.A., F.G.S., and John Scanes, Esq.

The following specimens and photographs were exhibited:—

Rock-specimens and Microscope-sections, exhibited by Prof. T. T. Groom, M.A., D.Sc., F.G.S., in illustration of his paper.

Rock-specimens, Fossils, and Photographs, exhibited by A. J. Jukes-Browne, Esq., B.A., F.G.S., and John Scanes, Esq., in illustration of their paper.

Boulder of Nepheline-Syenite-Pegmatite with Ægirine, found by Mr. Hinxman on the eastern slope of Coul More, probably derived from the plutonic mass of Cnoc na Sròine, 5 miles to the east, exhibited by the Director-General of H.M. Geological Survey.

Columnar Structure produced in Clay-Shale exposed on the pit-bank (refuse) of the Shipley Colliery, Derby, and subjected to the heat arising from the spontaneous combustion of the waste-heap, exhibited by the Rev. J. Magens Mello, M.A., F.G.S.

Photographs of Volcanic Vents in the Carboniferous Limestone Series at Grange Mill, 5 miles west of Matlock Bath (Derbyshire), photographed and exhibited by A. T. Metcalfe, Esq., F.G.S.

January 9th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Neil Dundonald Cochrane, Esq., Auckland (New Zealand); and Ebden Kemper-Voss, Esq., Assoc.R.S.M., 10 Rue de Namur, Brussels, were elected Fellows of the Society.

The following Fellows, nominated by the Council, were elected Auditors of the Society's accounts for the preceding year: Horace W. Monckton, Esq., F.L.S., and F. G. Hilton Price, Esq., F.S.A.

The List of Donations to the Library was read.

The following communications were read:—

1. 'Notes on the Geology of South-Central Ceylon.' By John Parkinson, Esq., F.G.S.

2. 'Note on the Occurrence of Corundum as a Contact-Mineral at Pont-Paul, near Morlaix (Finistère).' By A. K. Coomára-Swámy, Esq., B.Sc., F.L.S., F.G.S.

The following specimens, photographs, and maps were exhibited:—

Rock-specimens and Microscope-sections, exhibited by John Parkinson, Esq., F.G.S., in illustration of his paper.

Ellipsoidal inclusion in the Charnockite Series near Palakod, Salem District (Madras), exhibited by John Parkinson, Esq., F.G.S.

Rock-specimens, Microscope-sections, and Photographs of Sections, exhibited by A. K. Coomára-Swámy, Esq., B.Sc., F.L.S., F.G.S., in illustration of his paper.

Geological Survey 1-inch Maps, presented by the Director-General of that Survey:—England & Wales: n. s. Sheet 187. Huntingdon (Drift), by A. C. G. Cameron & C. B. Wedd; Ireland: Sheets 50 & 57. Down & Fermanagh, by F. W. Egan, and Sheet 90. Meath, by A. McHenry.

January 23rd, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

William Armstrong, Esq., Wingate Grange, Wingate, R.S.O. (Co. Durham); Alfred B. E. Blackburn, Esq., Old Bank House, Wednesbury; and J. Allen Howe, Esq., B.Sc., Assistant Demonstrator

in Geology in the Royal College of Science, South Kensington, were elected Fellows of the Society.

The List of Donations to the Library was read.

The PRESIDENT, having requested all those present to rise from their seats, said:

'I feel sure that the Fellows will desire to express their deep sense of the grievous loss which this nation has sustained in the death of our late beloved and most gracious Sovereign, by assenting to the immediate adjournment of the Meeting.'

The Meeting was accordingly adjourned.

February 6th, 1901.

J. J. H. TEALL, Esq., M.A., V.P.R.S., President, in the Chair.

Arthur Jodrell Bolton, Esq., 1 Armadale Road, Armadale (New South Wales); W. H. Cock, Esq., L.R.C.P., 40 Prospect Place, Swindon; the Rev. Percy Herbert Collins, M.A., Edgeborough, Guildford; James Reeve, Esq., Curator of the Castle Museum, Norwich; and Frederick Herbert Smith, Esq., Geological Survey of India, Calcutta, were elected Fellows of the Society.

The List of Donations to the Library was read.

Dr. F. A. BATHER, in exhibiting Rock-specimens, Microscope-sections, and Photographs illustrating Blavierite, Ophitic Diabase, Felsitic Porphyry, Petrosiliceous Breccia, and other Igneous and Metamorphic Rocks of the Mayenne, said that the specimens had been collected by him in the course of an excursion of the VIIIth International Geological Congress, under the guidance of M. D. P. Oehlert. In the basins of Laval and Coëvrons were many peculiar rocks due to the folding and crushing of stratified rocks penetrated by eruptive dykes. The tectonic features were illustrated by the maps of M. Oehlert and by the photographs. The slides were prepared in the Mineralogical Department of the Natural History Museum, where all the specimens would be preserved.

Mr. E. T. Newton exhibited some Graptolites, which had been obtained by Mr. Herbert J. Jessop in the course of a prospecting expedition in Eastern Peru. The locality was in lat. 13° 40′ S. and long. 72° 20′ W.; Limbani, near Crucero, in the neighbourhood of the Rio Inambari. The graptolites are closely related to *Diplograptus foliaceus* and indicate deposits of late Ordovician age.

Mr. A. K. Coomára-Swámy exhibited and commented on a lantern-slide showing Spherulitic Structure in Sulphanilic Acid. This had been described and figured by Mr. Henry Bassett, Jr., in the Geological Magazine for January, 1901, pp. 14–16.

The following communications were read:—

1. 'On the Structure and Affinities of the Rhætic Plant *Naiadita*.' By Miss Igerna B. J. Sollas, B.Sc., Newnham College, Cambridge. (Communicated by Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., V.P.G.S.)

2. 'On the Origin of the Dunmail Raise (Lake District).' By Richard D. Oldham, Esq., F.G.S.

In addition to the specimens, etc., mentioned above, the following were exhibited:—

Specimens and Lantern-slides exhibited by Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S., V.P.G.S., on behalf of Miss Igerna B. J. Sollas, B.Sc., and in illustration of her paper.

Photographs and Lantern-slides, exhibited by R. D. Oldham, Esq., F.G.S., in illustration of his paper.

Thirteen Platinotype Portraits of Fellows of the Society, presented by Messrs. Maull & Fox, Photographers.

ANNUAL GENERAL MEETING,

February 15th, 1901.

J. J. Harris Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Report of the Council for 1900.

The upward tendency of the number of Fellows, which has been a matter of congratulation in five successive Annual Reports, appears to have suffered a check during the past year, and a slight decrease has to be recorded. The undiminished financial prosperity of the Society, however, justifies the inference that the sources from which the Society's income is derived were in no way affected by the uncertain state of public affairs during 1900.

During the past twelve months 59 Fellows were elected into the Society (7 more than in 1899), of whom 40 paid their Admission Fees before the end of the year. Moreover, 7 Fellows who had been elected in the previous year paid their Admission Fees in 1900, the total accession of new Fellows during the year under review amounting therefore to 47.

On the other hand, there was a total loss of 57 Fellows during the past twelve months—40 by death, 11 by resignation, and 6 by removal from the List because of non-payment of their Annual Contributions.

From the foregoing statistics it will be seen that the actual decrease in the number of Fellows is 10 (as compared with an increase of 5 recorded in 1899).

Of the 40 Fellows deceased, 8 had compounded for their Annual Contributions, 26 were Contributing Fellows, and 6 were Non-contributing Fellows. On the other hand, 3 Fellows during the year under review became Compounders.

The total accession of Contributing Fellows is thus seen to be 44 (47 − 3), and the total loss being 43 (26 + 11 + 6), the number of Contributing Fellows during 1900 was increased by 1, as compared with an increase of 12 in 1899 and 13 in 1898.

With regard to the Lists of Foreign Members and Foreign Correspondents, it may be recollected that, at the end of 1899, there was no vacancy in the List of Foreign Members, and only

one in that of Foreign Correspondents. During the past twelve months the Society has suffered the loss, by death, of 3 of its Foreign Members. The vacancies thus arising were in part filled by the election of 3 Foreign Members and 3 Foreign Correspondents, but at the close of 1900 there still remained a vacancy in the List of Foreign Correspondents.

The total number of Fellows, Foreign Members, and Foreign Correspondents, which stood at 1344 on December 31st, 1899, had decreased to 1334 by the end of 1900.

Proceeding now to consider the Income and Expenditure of the Society during the past year, the figures set forth in detail in the Balance-Sheet may be summarized as follows:—

The total Receipts, including the Balance of £420 13*s*. 10*d*. brought forward from the previous year, amounted to £3450 13*s*. 1*d*., being £353 15*s*. 3*d*. more than the estimated Income. But this surplus includes the sum of £200 repaid to the Society by H.M. Treasury. This sum had been contributed by the Society in 1899 towards the cost of the improved lavatory accommodation at the Society's Apartments, and the question of repayment was still under the consideration of H.M. Treasury when the Estimates for 1900 were framed and issued to the Fellows.

The total Expenditure during 1900 amounted to £3061 18*s*. 3*d*., being £135 14*s*. 3*d*. more than the estimated Expenditure for the year. In the foregoing total is included a considerable item of non-recurring Expenditure, namely, the sum of £301 6*s*. 4*d*., expended on the completion of the Electric Lighting installation in the Society's Apartments. Mr. Musgrave Heaphy, C.E., F.G.S., kindly consented to place his invaluable experience once more at the disposal of the Society, and the whole system of the Electric Lighting installation was carefully planned by him, and carried out under his supervision, with thoroughly satisfactory results. For his great services in this matter, the Society owes him a deep debt of gratitude.

The Balance remaining available for the current year is £388 14*s*. 10*d*. This sum will go far towards meeting the expenditure which it is proposed to incur during the present year in connexion with the long-postponed Redecoration of the Society's Apartments, but it is estimated that between £100 and £200 more will be required to cover that item of Extraordinary Expenditure, to which the sanction of the Fellows is hereby requested.

The Council have pleasure in announcing the completion of Vol. LVI of the Society's Quarterly Journal, and the commencement of Vol. LVII. It will be observed that the cost of the Quarterly Journal for 1900, including the commission on sales, amounted to £989 18*s*. 4*d*., being £89 18*s*. 4*d*. more than the estimated Expenditure. As in the case, however, of the Volume for 1899, the Council feel assured that the Fellows will agree that

the great scientific value of the many important papers which Vol. LVI contains fully justifies the expenditure incurred in connexion with them.

It will be remembered that the Council undertook, on behalf of the Geological Society, to supply to the Regional Bureau of the International Catalogue of Scientific Literature, which begins with the new century, the material referring to geology published in the British Islands. Mr. C. Davies Sherborn, F.G.S., has been appointed by the Council to prepare and edit the Catalogue-slips necessary for that purpose.

As it appeared to be felt by many Fellows that some change in the details of procedure of the Annual General Meeting was desirable, the Council appointed a Committee to enquire into the subject. After careful investigation the Committee made a report to the Council, the conclusions of which were adopted as follows:—

1. That the Report of the Council be printed in advance, and distributed to the Fellows with the Balance-Sheet.
2. That Recipients of Awards be not expected to reply.
3. That Visitors be allowed to be present at the Annual General Meeting, if introduced by Fellows or Foreign Members, but that no Visitors be permitted to be present before 3.30 P.M., or so soon thereafter as the Discussion on the Report of the Council has been concluded.
4. That the Names of the Visitors and of the Fellows or Foreign Members introducing them be entered in a Book kept for the purpose.

The following Awards of Medals and Funds have been made by the Council:—

The Wollaston Medal is awarded to Prof. Charles Barrois, in recognition of the value of his researches concerning the Mineral Structure of the Earth, and, more particularly, of his masterly investigations among the Older Rocks of Britanny, by which he has so greatly added to the reputation already gained by his contributions to our knowledge of the Stratigraphy of the Cretaceous System of Britain.

The Murchison Medal, together with a sum of Ten Guineas from the Murchison Geological Fund, is awarded to Mr. Alfred John Jukes-Browne, in recognition of the value of his excellent work in Stratigraphical Geology, especially in the Cretaceous Rocks.

The Lyell Medal, with a sum of Twenty-five Pounds from the Lyell Geological Fund, is awarded to Dr. Ramsay Heatley Traquair, in recognition of the importance of his services to Palæontology, and particularly of his brilliant work among the Fossil Fishes.

The Bigsby Medal is awarded to Mr. George William Lamplugh, as an acknowledgment of his eminent services in Stratigraphical Geology, and particularly of his work on the Speeton Clay and in the Isle of Man.

The Balance of the Proceeds of the Wollaston Donation Fund is awarded to Mr. Arthur Walton Rowe, in recognition of his original and brilliant work on the Zones and Fossils of the British Chalk, and to encourage him in further research.

The Balance of the Proceeds of the Murchison Geological Fund is awarded to Mr. Thomas Sargeant Hall, in recognition of the value of his researches among the Graptolites and other Invertebrate Fossils of Australia, and to aid him in the further study of the Palæontology of the Southern Hemisphere.

A moiety of the Balance of the Lyell Geological Fund is awarded to Dr. John William Evans, in recognition of the work done by him in elucidating the Geology and Mineralogy of Kathiawar and other parts of India, and to encourage him in further investigations.

A moiety of the Balance of the Lyell Geological Fund is awarded to Mr. Alexander McHenry, in recognition of the value of his services in working out the Palæontology and Stratigraphy of Ireland, and to encourage him in further work.

Report of the Library and Museum Committee for 1900.

Although your Committee are unable to announce that the Additions made to the Library during the last year of the nineteenth century were greater than during any previous year of the Society's existence, they have nevertheless pleasure in stating that the Additions maintained, both in number and interest, the high standard to which the Society is accustomed. The number of Donors is the largest yet recorded.

During the past year the Library received by Donation 179 Volumes of separately published Works, 360 Pamphlets and detached Parts of Works, 182 Volumes and 142 detached Parts of Serial Publications (Transactions, Memoirs, Proceedings, etc.), and 17 Volumes of Newspapers.

The total number of accessions to the Library by Donation is thus seen to amount to 378 Volumes, 360 Pamphlets, and 142 detached Parts.

The number of Maps presented by various Donors surpasses even the exceptional record of the previous year, no less than 665 Sheets of Maps having been given to the Society's Library: about 397 of these are Ordnance Survey Maps. But the foregoing total is exclusive of the 21 folios of the Geologic Atlas of the United States which came in during 1900.

Although it is hardly possible to make a selection from among the numerous Donations (of which the totals have been recited in the foregoing paragraphs) without omitting many important gifts, your Committee may perhaps be allowed to direct attention to the following: Dr. C. W. Andrews's 'Monograph of Christmas Island' and Prof. J. W. Gregory's Catalogue of the Cretaceous Bryozoa, vol. i, both presented by the Trustees of the British Museum; Prof. R. Zeiller's 'Eléments de Paléobotanique'; Dr. D. H. Scott's 'Studies in Fossil Botany'; Prof. A. Rothpletz's 'Geologische Alpenforschungen'; the late Maurice Hovelacque's 'Album de Microphotographies des Roches Sédimentaires,' presented by his

widow; Prof. V. Sabatini's Memoir on the Volcanos of Central Italy; Messrs. Duparc, Pearce, & Ritter's Monograph on the Eruptive Rocks of Ménerville (Algeria); M. Coste's continuation of Gruner's great memoir on the Loire Coal-basin; and the following Memoirs of the Geological Survey: The Cretaceous Rocks of Britain, vol. i: Gault & Upper Greensand of England; Geology of the South Wales Coalfield, pt. ii—Abergavenny; and the Memoir on Atherstone & Charnwood. Moreover, numerous publications were received from the Geological Survey Departments of India, Denmark, and Sweden.

An extremely valuable and interesting donation was made to the Library by Mrs. Katherine Lyell, in the shape of the MS. Volume of Notes on the Huttonian Theory compiled by the late Leonard Horner.

Turning again to the Maps, besides the Geologic Atlas of the United States, previously mentioned, the following Donations are noteworthy: Geological Survey Map of South Australia in 4 sheets; 3 sheets of the Geological Survey Map of Western Australia; 244 sheets (topographical and geological) of the Maps of the United States Geological Survey; 8 sheets of Maps of the Geological Surveys of Canada, Denmark, Portugal, and Spain; and 9 sheets of Maps of the Geological Surveys of England & Wales and Ireland.

The Books and Maps enumerated above were the gift of 186 Personal Donors; 101 Government Departments and other Public Bodies; and 174 Societies and Editors of Periodicals.

The Purchases made on the recommendation of the standing Library Committee comprised 54 Volumes and 11 Parts of separately published Works; 25 Volumes and 12 Parts of works published serially; and 22 Sheets of Maps.

A communication having been received in April last from the Secretary of the Geological Photographs Committee of the British Association, it was resolved to subscribe to the annual series of Mounted Photographs.

The total Expenditure incurred in connexion with the Library during 1900 was as follows:—

	£	s.	d.
Books, Periodicals, etc. purchased..........	63	17	8
Binding of Books and Mounting of Maps....	150	1	7
	£213	19	3

The Society's Collection of Portraits of eminent Geologists has been enriched by the following Donations: Framed Photograph of Messrs. Searles Wood, father and son, presented by Mr. F. W. Harmer; and a Framed Photograph of the late Dr. Henry Hicks, F.R.S., presented by Mrs. Hicks.

Museum.

No addition has been made to the Collections during the past year, and no Expenditure has been incurred in connexion with them.

On February 10th, 1900, the Collections were thrown open to the inspection of the Geologists' Association, and thanks were voted to this Society for the hospitality extended to the Association on that occasion.

For the purpose of study and comparison the Collections were examined on nine different occasions during the year, about 80 drawers being had out for that purpose.

The appended Lists contain the Names of Government Departments, Public Bodies, Societies, Editors, and Personal Donors, from whom Donations to the Library have been received during the year under review :—

I. Government Departments and other Public Bodies.

Alabama Geological Survey. University (Ala.).
American Museum of Natural History. New York.
Argentine Government.
Athens.—Observatoire National d'Athènes.
Augustana Library. Rock Island (Ill.).
Australian Museum. Sydney.
Austria.—Kaiserlich-königliche Geologische Reichsanstalt. Vienna.
——. Kaiserlich-königliches Naturhistorisches Hofmuseum. Vienna.
Bavaria.—Königlich Bayerisches Oberbergamt. Munich.
Belgium.—Académie Royale des Sciences, des Lettres & des Beaux-Arts de Belgique. Brussels.
Berlin.—Königliche Preussische Akademie der Wissenschaften.
——. Königliche Preussische Geologische Landesanstalt.
Birmingham University.
Bohemia.—Musée d'Histoire Naturelle. Prague.
British Guiana.—Department of Mines.
British South Africa Company. London.
Buenos Aires.—Museo Nacional.
California.—State Mining Bureau. San Francisco.
California University. Berkeley.
Cambridge (Mass.).—Museum of Comparative Zoology, Harvard College.
Canada.—Geological & Natural History Survey. Ottawa.
Chicago.—'Field' Columbian Museum.
Denmark.—Danish Ingolf Expedition.
——. Danmarks Geologiske Undersögelse. Copenhagen.
——. Kongelige Danske Videnskabernes Selskab. Copenhagen.
Dublin.—Royal Irish Academy.
Egypt.—Geological Survey.
Finland.—Finlands Geologiska Undersökning. Helsingfors.
France.—Dépôt de la Marine. Paris.
——. Ministère des Travaux Publics. Paris.
——. Muséum d'Histoire Naturelle. Paris.

Germany.—Kaiserliche Leopoldinisch-Carolinische Deutsche Akademie der Naturforscher. Halle.
Great Britain.—Army Medical Department. London.
——. British Museum (Natural History). London.
——. Colonial Office. London.
——. Geological Survey. London.
——. Home Office. London.
——. Ordnance Survey. Southampton.
Holland.—Departement van Kolonien. The Hague.
Hungary.—Königliche Ungarische Geologische Anstalt (Magyar Földtani Tarsulat). Budapest.
India.—Geological Survey. Calcutta.
——. Indian Museum. Calcutta.
Indiana.—Department of Geology. Indianapolis.
Italy.—Reale Comitato Geologico. Rome.
Jassy, University of.
Kansas.—University Geological Survey. Topeka.
Kingston (Canada).—Queen's College.
La Plata Museum. La Plata.
London.—City of London College.
——. Royal College of Surgeons.
——. University College.
Louisiana.—Geological Survey. Bâton Rouge (La).
Madrid.—Real Academia de Ciencias Exactas, Fisicas & Naturales.
Maryland Geological Survey. Baltimore.
Mexico.—Instituto Geologico. Mexico City.
Michigan College of Mines. Houghton.
Michigan Geological Survey.
Milwaukee.—Public Museum of the City of Milwaukee.
Minnesota.—Geological & Natural History Survey. Minneapolis.
Munich.—Königliche Bayerische Akademie der Wissenschaften.
New South Wales.—Agent-General for, London.
——. Department of Lands. Sydney.
——. Department of Mines & Agriculture. Sydney.
——. Geological Survey. Sydney.
New York Museum. Albany.
New Zealand.—Department of Mines. Wellington.
Norway.—Meteorological Department. Christiania.
Paris.—Académie des Sciences.
Perak Government. Taiping.
Pisa.—Royal University.
Portugal.—Commissão Geologica. Lisbon.
Prussia.—Ministerium für Handel & Gewerbe. Berlin.
Queensland.—Agent-General for, London.
——. Department of Mines. Brisbane.
——. Geological Survey. Brisbane.
Rome.—Reale Accademia dei Lincei.
Rumania.—Museum of Geology & Palæontology. Bucharest.
Russia.—Comité Géologique. St. Petersburg.
——. Section Géologique du Cabinet de S.M. l'Empereur. St. Petersburg.
São Paulo.—Commissão Geographica & Geologica de São Paulo.
South Australia.—Agent-General for, London.
——. Government Geologist. Adelaide.
Spain.—Comision del Mapa Geológico. Madrid.
St. Petersburg.—Académie Impériale des Sciences.
Stockholm.—Kongliga Svenska Vetenskaps Akademi.
Sweden.—Sveriges Geologiska Undersökning. Stockholm.
Tokio.—Imperial University.
——. College of Science.
Tufts College (Mass.). Tufts College.
Turin.—Reale Accademia delle Scienze.
United States.—Geological Survey. Washington.
——. Department of Agriculture. Washington.
——. National Museum. Washington.
Upsala University.
—— ——. Mineralogical & Geological Institute.
Vienna.—Kaiserliche Akademie der Wissenschaften.

Washington (D.C.).—Smithsonian Institution.
West Virginia.—Geological Survey. Morgantown.
Western Australia.—Agent-General for, London.
——. Department of Mines. Perth.
——. Geological Survey. Perth.

II. Societies and Editors.

Acireale.—Accademia di Scienze, Lettere & Arti.
Adelaide.—Royal Society of South Australia.
Agram.—Societas Historico-Naturalis Croatica.
Alnwick.—Berwickshire Naturalists' Club.
Auckland.—New Zealand Institute of Mining Engineers.
Bahia.—Instituto Geographico & Historico.
Barnsley.—Midland Institute of Mining, Civil, & Mechanical Engineers.
Bath.—Natural History & Antiquarian Field Club.
Belfast.—Natural History & Philosophical Society.
Berlin.—Deutsche Geologische Gesellschaft.
——. Gesellschaft Naturforschender Freunde.
——. Zeitschrift für Praktische Geologie.
Berne.—Schweizerische Naturforschende Gesellschaft.
Bombay Branch of the Royal Asiatic Society.
Bordeaux.—Société Linnéenne.
Boston (Mass.).—American Academy of Arts & Sciences.
Boston Society of Natural History.
Brunswick.—Verein für Naturwissenschaft zu Braunschweig.
Brussels.—Société Belge de Géologie, de Paléontologie & d'Hydrologie.
——. Société Malacologique de Belgique.
Budapest.—Földtani Közlöny (Geological Magazine).
Buenos Aires.—Instituto Geografico Argentino.
——. Sociedad Científica Argentina.
Calcutta.—Indian Engineering.
——. Asiatic Society of Bengal.
Cambridge.—Philosophical Society.
Cape Town.—South African Philosophical Society.
Cardiff.—South Wales Institute of Engineers.
Chicago.—Academy of Sciences.
——. Journal of Geology.
Cincinnati Society of Natural History.
Colombo.—Ceylon Branch of the Royal Asiatic Society.
Colorado Springs.—Colorado College Studies.
Copenhagen.—Dansk Geologisk Forening.
Córdoba (Argentine Republic).—Academia Nacional de Ciencias.
Cracow.—Académie des Sciences (Akademja Umiejetosci).
Croydon Microscopical & Natural History Club.
Darmstadt.—Verein für Erdkunde.
Davenport (Iowa).—Academy of Natural Sciences.
Denver (Colo.).—Colorado Scientific Society.
Dorpat.—Naturforschende Gesellschaft.
Douglas.—Isle of Man Natural History & Antiquarian Society.
Dresden.—Naturwissenschaftliche Gesellschaft 'Isis.'
Dublin.—Royal Dublin Society.
Edinburgh.—Geological Society.
——. Royal Physical Society.
——. Royal Scottish Geographical Society.
——. Royal Society.
——. Scottish Natural History Society.
Ekaterinburg.—Société Ouralienne d'Amateurs des Sciences Naturelles.
Frankfurt am Main.—Senckenbergische Naturforschende Gesellschaft.
Freiburg im Breisgau.—Naturforschende Gesellschaft.
Geneva.—Société Physique & d'Histoire Naturelle.
Giessen.—Oberhessische Gesellschaft für Natur- & Heilkunde.
Gratz.—Naturwissenschaftlicher Verein für Steiermark.
Haarlem.—Société Hollandaise des Sciences.

Halifax.—Yorkshire Geological & Polytechnic Society.
—— (N. S.).—Nova Scotian Institute of Science.
Hamilton (Canada).—Hamilton Association.
Hanau.—Wetterauische Gesellschaft für Gesammte Naturkunde.
Helsingfors.—Geografiska Förening i Finland.
Hermannstadt.—Siebenbürgischer Verein für Naturwissenschaften.
Hertford.—Hertfordshire Natural History Society.
Hull.—Scientific & Naturalists' Club.
Kiev.—Société des Naturalistes.
Lausanne.—Société Vaudoise des Sciences Naturelles.
Lawrence.—Kansas University Quarterly.
Leicester.—Literary & Philosophical Society.
Leipzig.—Zeitschrift für Krystallographie & Mineralogie.
Liége.—Société Géologique de Belgique.
Lille.—Société Géologique du Nord.
Lima.—Revista de Ciencias.
Lisbon.—Sociedade de Geographia.
Liverpool.—Geological Society.
London.—'Academy.'
——. 'Athenæum.'
——. British Association for the Advancement of Science.
——. British Association of Waterworks Engineers.
——. 'Chemical News.'
——. Chemical Society.
——. 'Colliery Guardian.'
——. East India Association.
——. 'Geological Magazine.'
——. Geologists' Association.
——. Institution of Civil Engineers.
——. Iron & Steel Institute.
——. 'Iron & Steel Trades' Journal.'
——. 'Knowledge.'
——. Linnean Society.
——. 'London, Edinburgh, & Dublin Philosophical Magazine.'
——. Mineralogical Society.
——. 'Nature.'
——. Palæontographical Society.
——. 'Quarry.'
——. Ray Society.
——. Royal Agricultural Society.
——. Royal Astronomical Society.
——. Royal Geographical Society.
——. Royal Institution.
——. Royal Meteorological Society.
——. Royal Microscopical Society.
——. Royal Photographic Society of Great Britain.
——. Royal Society.
——. Society of Arts.
——. Society of Biblical Archæology.
——. Society of Public Analysts.
——. Victoria Institute.
——. 'Water.'
——. Zoological Society.
Madison.—Wisconsin Academy of Sciences.
Manchester.—Geological Society.
——. Literary & Philosophical Society.
Mexico.—Sociedad Científica 'Antonio Alzate.'
Milan.—Reale Istituto Lombardo di Scienze e Lettere.
Montreal.—Natural History Society.
Moscow.—Société Impériale des Naturalistes.
Nancy.—Académie de Stanislas.
New Haven (Conn.).—American Journal of Science.
——. Connecticut Academy of Sciences.
New York.—Academy of Sciences.
——. American Institute of Mining Engineers.
Newcastle-upon-Tyne.—Institution of Mining Engineers.
——. North of England Institute of Mining & Mechanical Engineers.

Northampton.—Northamptonshire Natural History Society.
Nürnberg.—Naturhistorische Gesellschaft.
Ottawa.—Royal Society of Canada.
Padua.—Reale Accademia di Scienze, Lettere & Arti.
Palermo.—Annales de Géologie & de Paléontologie.
Paris.—'Revue Scientifique.'
——. Société Française de Minéralogie.
——. Société Géologique de France.
——. 'Spelunca.'
Penzance.—Royal Geological Society of Cornwall.
Perth.—Perthshire Society of Natural Science.
Philadelphia.—Academy of Natural Sciences.
——. American Philosophical Society.
——. Wagner Free Institute of Science.
Pisa.—Società Toscana di Scienze Naturali.
Plymouth.—Devonshire Association for the Advancement of Science.
Rochester (N.Y.).—Geological Society of America.
Rome.—Società Geologica Italiana.
Rugby School Natural History Society.
Salem (Mass.).—Essex Institute.
Santiago de Chile.—Deutscher Wissenschaftlicher Verein.
——. Sociedad Nacional de Mineria.
——. Société Scientifique du Chili.
Scranton (Pa.).—'Mines & Minerals.'
Shanghai.—China Branch of the Royal Asiatic Society.
Spezia.—Società Gerolamo Guidoni.
St. John.—Natural History Society of New Brunswick.
St. Petersburg.—Académie Impériale des Sciences.
——. Russische Kaiserliche Mineralogische Gesellschaft.
Stockholm.—Geologiska Förening.
Stuttgart.—Centralblatt für Mineralogie, Geologie & Paläontologie.
——. Neues Jahrbuch für Mineralogie, Geologie & Paläontologie.
——. Verein für Vaterländische Naturkunde in Württemberg.
——. Zeitschrift für Naturwissenschaften.
Sydney.—Australasian Association for the Advancement of Science.
——. Australasian Institute of Mining Engineers.
——. Linnean Society of New South Wales.
——. Royal Society of New South Wales.
Tokio.—Earthquake Investigation Committee.
Topeka (Kan.).—Kansas Academy of Sciences.
Toronto.—Canadian Institute.
Toulouse.—Société d'Histoire Naturelle.
Truro.—Royal Institution of Cornwall.
Vienna.—Berg- & Hüttenmännisches Jahrbuch.
——. Kaiserlich-Königliche Zoologisch-Botanische Gesellschaft.
Washington (D.C.).—Academy of Sciences.
——. Biological Society.
Wellington (N.Z.).—New Zealand Institute.
Wiesbaden.—Nassauischer Verein für Naturkunde.
Winnipeg.—Historical & Scientific Society of Manitoba.
York.—Yorkshire Philosophical Society.

III. Personal Donors.

Agassiz, A.
Alford, C. J.
Allen, H.
Ameghino, F.
Ami, H.
Anderson, J. G.
Andrews, W.
Angelis d'Ossat, G. de.
Avebury, Rt. Hon. Lord.

Balch, E. S.
Barrett, R. L.
Beecher, C. E.
Belinfante, L. L.
Blake, W. P.
Bleicher, —.
Böckh, J.
Bodenbender, G.
Bœggild, O. B.
Bogoslovski, N.
Böhm, A. von.
Bonney, T. G.
Boule, M.
Branner, J. C.
Brillouin, M.
Brough, B. H.
Brown, H. Y. L.
Buckman, S. S.

Carne, J. E.
Choffat, P.
Clark, W. B.
Claypole, E. W.

Cole, G. A. J.
Collett, O.
Coomára-Swámy, A. K.
Cort, H. de.
Credner, H.
Crick, G. C.

Dalton, W. H.
Datta, P. N.
Davis, W. M.
Davison, C.
Delgado, J. F. N.
Dewalque, G.
Donald, J.
Donville, H.
Douglass, E.
Doyle, P.
Dunn, E. J.
Duparc, L.

Eginitis, D.
Emmons, S. F.
Evans, Sir John.
Evans, J. W.
Evans, T.

Fletcher, H.
Forir, H.
Foster, C. Le N.
Fox, H.
Francis, W.
Frazer, P.

Galloway, W. B.
Gavelin, A.
Geinitz, F. E.
Gilpin, E., Junr.
Gosselet, J.
Gray, J.
Greenwell, A.
Gregorio, Marquis A. de.
Gresley, W. S.
Griffith, P.
Groom, T. T.
Grünling, F.
Gulliver, F. P.
Günther, A.

Harker, A.
Harlé, E.
Harmer, F. W.
Harrison, J. B.
Hall, W. J.
Hatch, F. H.
Hicks, Mrs.
Hind, W.
Hinde, G. J.
Hingenau, O. von.
Holland, T. H.

Honoré, C.
Hovelacque, Mme. M.
Hovey, E. O.
Hubbard, L. L.
Hull, E.

Jennings, A. V.
Jensen, A. S.
Jones, T. R.

Karrer, F.
Kayser, E.
Koch, A.
Kœnen, A. von.
Kornerup, T.
Krausé, F. M.

Lacroix, A.
Lamarre-Olivier, A.
Lambert, G.
Lamplugh, G. W.
Lane, A. C.
Lapparent, A. de.
Lebesconte, P.
Lee, J. B.
Lindström, G.
Lœwinson-Lessing, F.
Lohest, M.
Lones, T. E.
Loriol, P. de.
Lotz, H.
Louis, D. A.
Lyell, Mrs. K.

Maitland, A. G.
Mansel-Pleydell, J. C.
Marr, J. E.
Martin, E. A.
Matley, C. A.
Millosevich, F.
Mojsisovics, E. von.
Monckton, H. W.
Möller, H.
Mourlon, M.

Nares, Sir George S.
Nathorst, A. G.
Newton, R. B.
Nicolis, E.
Nordenskiöld, Baron Adolf Erik.
Nordenskiöld, O.

Ordoñez, E.

Packard, A. S.
Pearce, F.
Perkins, H. I.
Power, F. D.

Radovanovich, S.
Reade, T. M.
Renevier, E.
Reusch, H.
Richthofen, Baron Ferdinand von.
Ritter, E.
Ritter, L.
Roechling, H. A.
Rosenbusch, H.
Rothpletz, A.
Rowe, A. W.
Rudzki, P.
Rutley, F.

Sacco, F.
Salter, A. E.
Sarasin, C.
Schardt, H.
Scott, D. H.
Seward, A. C.
Sheppard, T.
Sjögren, H.
Smyth, B. B.
Stefanescu, G.
Strachey, Sir Richard.

Talmage, J. E.
Thompson, B.
Thugutt, St. J.
Tietze, E.
Trener, G. B.
Tucker, W. T.

Upton, C.

Van den Broeck, E.
Veitch, A. C.
Vernon-Harcourt, L. F.
Vincent, M. C.

Walther, J.
Ward, J.
Wardle, Sir Thomas.
Watts, W. W.
Weinschenk, E.
Wellburn, E. D.
Whitaker, W.
Whitfield, P. P.
Whitney, M.
Wiman, C.
Winchell, N. H.
Woods, H.
Woodward, Henry.

Zeiller, R.
Zelizko, J. V.

Comparative Statement of the Number of the Society at the Close of the Years 1899 and 1900.

	Dec. 31st, 1899.		Dec. 31st, 1900.
Compounders	288	......	283
Contributing Fellows	923	......	924
Non-contributing Fellows	54	......	48
	1265		1255
Foreign Members	40	......	40
Foreign Correspondents	39	......	39
	1344		1334

Comparative Statement explanatory of the Alterations in the Number of Fellows, Foreign Members, and Foreign Correspondents at the close of the years 1899 and 1900.

Number of Compounders, Contributing and Non-contributing Fellows, December 31st, 1899 ..			1265
Add Fellows elected during the former year and paid in 1900			7
Add Fellows elected and paid in 1900			40
			1312
Deduct Compounders deceased		8	
Contributing Fellows deceased		26	
Non-contributing Fellows deceased		6	
Contributing Fellows resigned		11	
Contributing Fellows removed		6	
		—	57
			1255
Number of Foreign Members and Foreign Correspondents, December 31st, 1899		79	
Deduct Foreign Members deceased	3		
Foreign Correspondents elected Foreign Members	3		
	—	6	
		73	
Add Foreign Members elected	3		
Foreign Correspondents elected	3		
	—	6	
		—	79
			1334

Deceased Fellows.

Compounders (8).

Jones, T. M., Esq.
Lindley, W., Esq.
Maclean, W. C., Esq.
Middleton, J. O., Esq.
Pearce, H., Esq.
Prevost, Col. L. de T.
Rylands, T. G., Esq.
Young, Dr. John.

Resident and other Contributing Fellows (26).

Anstie, J., Esq.
Argyll, Duke of.
Armstrong, Prof. G. F.
Atkinson, H. K., Esq.
Branscombe, W. H., Esq.
Candler, T. E., Esq.
Garlick, E., Esq.
Greenwell, G. C., Esq. (Duffield).
Grimston, Capt. the Hon. William.
Maggs, T. C., Esq.
Meyer, C. J. A., Esq.
Petrie, Capt. F. W. H.
Pidgeon, D., Esq.
Pitt-Rivers, Lt.-Gen. A. H. Lane-Fox.
Pritchard, E., Esq.
Prout, T. P., Esq.
Robinson, J. T., Esq.
Ross, Capt. G. E. A.
Ruskin, Prof. John.
Russell, R., Esq.
Sladen, W. P., Esq.
Thomson, J., Esq.
Ulrich, Prof. G. H. F.
Waagen, Dr. W.
Walker, H., Esq.
White, H., Esq.

Non-contributing Fellows (6).

Fletcher, W., Esq.
Hill, Canon Edward.
Lowe, E. J., Esq.
McLandsborough, J., Esq.
Morton, G. H., Esq.
Tylden-Wright, C., Esq.

Deceased Foreign Members (3).

Geinitz, Prof. H. B.
Milne-Edwards, Prof. A.
Torell, Prof. O. M.

Fellows Resigned (11).

Barham, H. G. F., Esq.
Beaumont, W. W., Esq.
Brown, T. Forster, Esq.
Burrow, J. C., Esq.
Galton, F., Esq.
Hall, Rev. H. A.
Hamilton, J. J., Esq.
Main, J., Esq.
Mosley, G., Esq.
Scamell, G., Esq.
Walker, G. B., Esq.

FELLOWS REMOVED (6).

	Ford, S. W., Esq.
	Heussler, C. A., Esq.
Esq.	Officer, Major C. M.

...owing Personages were elected Foreign Members during the year 1900:—

M. Gustave F. Dollfus, of Paris.
Prof. Paul Groth, of Munich.
Dr. Sven Leonhard Törnquist, of Lund.

The following Personages were elected Foreign Correspondents during the year 1900:—

Prof. Arturo Issel, of Genoa.
Prof. Ernst Koken, of Tübingen.
Prof. Federico Sacco, of Turin.

After the Reports had been read, it was resolved:—

That they be received and entered on the Minutes of the Meeting, and that such parts of them as the Council shall think fit be printed and circulated among the Fellows.

It was afterwards resolved:—

That the thanks of the Society be given to Prof. J. W. Judd and Prof. W. J. Sollas, retiring from the office of Vice-President.

That the thanks of the Society be given to Prof. T. G. Bonney, F. W. Harmer, Esq., the Rev. Edwin Hill, the Rev. H. H. Winwood, and Dr. A. Smith Woodward, retiring from the Council.

After the Balloting-glasses had been closed, and the Lists examined by the Scrutineers, the following gentlemen were declared to have been duly elected as the Officers and Council for the ensuing year:—

OFFICERS AND COUNCIL.—1901.

PRESIDENT.

J. J. H. Teall, Esq., M.A., V.P.R.S.

VICE-PRESIDENTS.

J. E. Marr, Esq., M.A., F.R.S.
H. W. Monckton, Esq., F.L.S.
Prof. H. G. Seeley, F.R.S., F.L.S.
W. Whitaker, Esq., B.A., F.R.S.

SECRETARIES.

R. S. Herries, Esq., M.A.
Prof. W. W. Watts, M.A.

FOREIGN SECRETARY.

Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S., F.L.S.

TREASURER.

W. T. Blanford, LL.D., F.R.S.

COUNCIL.

W. T. Blanford, LL.D., F.R.S.
Sir John Evans, K.C.B., D.C.L., LL.D., F.R.S.
Prof. E. J. Garwood, M.A.
Prof. T. T. Groom, M.A., D.Sc.
Alfred Harker, Esq., M.A.
R. S. Herries, Esq., M.A.
William Hill, Esq.
W. H. Hudleston, Esq., M.A., F.R.S., F.L.S.
Prof. J. W. Judd, C.B., LL.D., F.R.S.
Lieut.-General C. A. McMahon, F.R.S.
J. E. Marr, Esq., M.A., F.R.S.
Prof. H. A. Miers, M.A., F.R.S.
Right Rev. John Mitchinson, D.D., D.C.L.
H. W. Monckton, Esq., F.L.S.
E. T. Newton, Esq., F.R.S.
G. T. Prior, Esq., M.A.
F. W. Rudler, Esq.
Prof. H. G. Seeley, F.R.S., F.L.S.
Prof. W. J. Sollas, M.A., D.Sc., LL.D., F.R.S.
J. J. H. Teall, Esq., M.A., V.P.R.S.
Prof. W. W. Watts, M.A.
W. Whitaker, Esq., B.A., F.R.S.
H. B. Woodward, Esq., F.R.S.

LIST OF

THE FOREIGN MEMBERS

OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1900.

Date of Election.

1857. Prof. Hanns Bruno Geinitz, *Dresden*. (*Deceased.*)
1874. Prof. Albert Gaudry, *Paris*.
1877. Prof. Eduard Suess, *Vienna*.
1880. Prof. Gustave Dewalque, *Liége*.
1880. Baron Adolf Erik Nordenskiöld, *Stockholm*.
1880. Prof. Ferdinand Zirkel, *Leipzig*.
1883. Prof. Otto Martin Torell, *Stockholm*. (*Deceased.*)
1884. Prof. G. Capellini, *Bologna*.
1885. Prof. Jules Gosselet, *Lille*.
1886. Prof. Gustav Tschermak, *Vienna*.
1887. Prof. J. P. Lesley, *Philadelphia, Pa., U.S.A.*
1888. Prof. Eugène Renevier, *Lausanne*.
1888. Baron Ferdinand von Richthofen, *Berlin*.
1889. Prof. Ferdinand Fouqué, *Paris*.
1889. Geheimrath Prof. Karl Alfred von Zittel, *Munich*.
1890. Prof. Heinrich Rosenbusch, *Heidelberg*.
1891. Prof. Charles Barrois, *Lille*.
1892. Prof. Gustav Lindström, *Stockholm*.
1893. Prof. Waldemar Christofer Brögger, *Christiania*.
1893. M. Auguste Michel-Lévy, *Paris*.
1893. Dr. Edmund Mojsisovics von Mojsvár, *Vienna*.
1893. Dr. Alfred Gabriel Nathorst, *Stockholm*.
1894. Prof. George J. Brush, *New Haven, Conn., U.S.A.*
1894. Prof. Edward Salisbury Dana, *New Haven, Conn., U.S.A.*
1894. Prof. Alphonse Renard, *Ghent*.
1895. Prof. Grove K. Gilbert, *Washington, D.C., U.S.A.*
1895. M. Friedrich Schmidt, *St. Petersburg*.
1896. Prof. Albert Heim, *Zürich*.
1897. M. E. Dupont, *Brussels*.
1897. Dr. Anton Fritsch, *Prague*.
1897. Prof. A. de Lapparent, *Paris*.
1897. Dr. Hans Reusch, *Christiania*.
1898. Geheimrath Prof. Hermann Credner, *Leipzig*.
1898. Mr. Charles D. Walcott, *Washington, D.C., U.S.A.*
1899. Prof. Marcel Bertrand, *Paris*.
1899. Senhor J. F. N. Delgado, *Lisbon*.
1899. Prof. Emmanuel Kayser, *Marburg*.
1899. Prof. Alphonse Milne-Edwards, *Paris*. (*Deceased.*)
1899. M. Ernest Van den Broeck, *Brussels*.
1899. Dr. Charles Abiathar White, *Washington, D.C., U.S.A.*
1900. M. Gustave F. Dollfus, *Paris*.
1900. Prof. Paul Groth, *Munich*.
1900. Dr. Sven Leonhard Törnquist, *Lund*.

LIST OF
THE FOREIGN CORRESPONDENTS
OF THE GEOLOGICAL SOCIETY OF LONDON, IN 1900.

Date of Election.

1866. Prof. Victor Raulin, *Montfaucon d'Argonne.*
1874. Prof. Igino Cocchi, *Florence.*
1879. Dr. Émile Sauvage, *Boulogne-sur-Mer.*
1889. M. R. D. M. Verbeek, *Buitenzorg, Java.*
1890. Herr Felix Karrer, *Vienna.*
1890. Prof. Adolph von Kœnen, *Göttingen.*
1892. Prof. Johann Lehmann, *Kiel.*
1892. Major John W. Powell, *Washington, D.C., U.S.A.*
1893. Prof. Aléxis Pavlow, *Moscow.*
1893. M. Ed. Rigaux, *Boulogne-sur-Mer.*
1894. Prof. Joseph Paxson Iddings, *Chicago, Ill., U.S.A.*
1894. M. Perceval de Loriol-Lefort, *Campagne Frontenex.*
1894. Dr. Francisco P. Moreno, *La Plata.*
1894. Prof. August Rothpletz, *Munich.*
1894. Prof. J. H. L. Vogt, *Christiania.*
1895. Prof. Konstantin de Kroustchoff, *St. Petersburg.*
1895. Prof. Albrecht Penck, *Vienna.*
1896. Prof. S. L. Penfield, *New Haven, Conn., U.S.A.*
1896. Prof. Johannes Walther, *Jena.*
1897. M. Louis Dollo, *Brussels.*
1897. Mr. Alpheus Hyatt, *Cambridge, Mass., U.S.A.*
1897. Prof. Anton Koch, *Budapest.*
1897. Prof. A. Lacroix, *Paris.*
1897. M. Emmanuel de Margerie, *Paris.*
1897. Prof. Count H. zu Solms-Laubach, *Strasburg.*
1898. M. Marcellin Boule, *Paris.*
1898. Dr. W. H. Dall, *Washington, D.C., U.S.A.*
1898. M. A. Karpinsky, *St. Petersburg.*
1899. Prof. Charles Emerson Beecher, *New Haven, U.S.A.*
1899. Dr. Gerhard Holm, *Stockholm.*
1899. Prof. Theodor Liebisch, *Göttingen.*
1899. Prof. Franz Lœwinson-Lessing, *Dorpat.*
1899. M. Michel F. Mourlon, *Brussels.*
1899. Prof. Henry Fairfield Osborn, *New York, U.S.A.*
1899. Prof. Gregorio Stefanescu, *Bucharest.*
1899. Prof. René Zeiller, *Paris.*
1900. Prof. Arturo Issel, *Genoa.*
1900. Prof. Ernst Koken, *Tübingen.*
1900. Prof. Federico Sacco, *Turin.*

AWARDS OF THE WOLLASTON MEDAL

UNDER THE CONDITIONS OF THE 'DONATION FUND'

ESTABLISHED BY

WILLIAM HYDE WOLLASTON, M.D., F.R.S., F.G.S., ETC.

'To promote researches concerning the mineral structure of the earth, and to enable the Council of the Geological Society to reward those individuals of any country by whom such researches may hereafter be made,'—'such individual not being a Member of the Council.'

1831. Mr. William Smith.
1835. Dr. G. A. Mantell.
1836. M. Louis Agassiz.
1837. { Capt. T. P. Cautley. / Dr. H. Falconer.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Prof. A. H. Dumont.
1841. M. Adolphe T. Brongniart.
1842. Baron L. von Buch.
1843. { M. Élie de Beaumont. / M. P. A. Dufrénoy.
1844. Rev. W. D. Conybeare.
1845. Prof. John Phillips.
1846. Mr. William Lonsdale.
1847. Dr. Ami Boué.
1848. Very Rev. W. Buckland.
1849. Sir Joseph Prestwich.
1850. Mr. William Hopkins.
1851. Rev. Prof. A. Sedgwick.
1852. Dr. W. H. Fitton.
1853. { M. le Vicomte A. d'Archiac. / M. E. de Verneuil.
1854. Sir Richard Griffith.
1855. Sir Henry De la Beche.
1856. Sir William Logan.
1857. M. Joachim Barrande.
1858. { Herr Hermann von Meyer. / Prof. James Hall.
1859. Mr. Charles Darwin.
1860. Mr. Searles V. Wood.
1861. Prof. Dr. H. G. Bronn.
1862. Mr. R. A. C. Godwin-Austen.
1863. Prof. Gustav Bischof.
1864. Sir Roderick Murchison.
1865. Dr. Thomas Davidson.
1866. Sir Charles Lyell.
1867. Mr. G. Poulett Scrope.
1868. Prof. Carl F. Naumann.
1869. Dr. Henry C. Sorby.
1870. Prof. G. P. Deshayes.
1871. Sir Andrew Ramsay.
1872. Prof. James D. Dana.
1873. Sir P. de M. Grey Egerton.
1874. Prof. Oswald Heer.
1875. Prof. L. G. de Koninck.
1876. Prof. Thomas H. Huxley.
1877. Mr. Robert Mallet.
1878. Dr. Thomas Wright.
1879. Prof. Bernhard Studer.
1880. Prof. Auguste Daubrée.
1881. Prof. P. Martin Duncan.
1882. Dr. Franz Ritter von Hauer.
1883. Dr. W. T. Blanford.
1884. Prof. Albert Gaudry.
1885. Mr. George Busk.
1886. Prof. A. L. O. Des Cloizeaux.
1887. Mr. J. Whitaker Hulke.
1888. Mr. H. B. Medlicott.
1889. Prof. Thomas G. Bonney.
1890. Prof. W. C. Williamson.
1891. Prof. John W. Judd.
1892. Baron Ferdinand von Richthofen.
1893. Prof. Nevil S. Maskelyne.
1894. Prof. Karl Alfred von Zittel.
1895. Sir Archibald Geikie.
1896. Prof. Eduard Suess.
1897. Mr. Wilfrid H. Hudleston.
1898. Prof. Ferdinand Zirkel.
1899. Prof. Charles Lapworth.
1900. Prof. Grove K. Gilbert.
1901. Prof. Charles Barrois.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE WOLLASTON 'DONATION FUND.'

1831. Mr. William Smith.
1833. Mr. William Lonsdale.
1834. M. Louis Agassiz.
1835. Dr. G. A. Mantell.
1836. Prof. G. P. Deshayes.
1838. Sir Richard Owen.
1839. Prof. C. G. Ehrenberg.
1840. Mr. J. De Carle Sowerby.
1841. Prof. Edward Forbes.
1842. Prof. John Morris.
1843. Prof. John Morris.
1844. Mr. William Lonsdale.
1845. Mr. Geddes Bain.
1846. Mr. William Lonsdale.
1847. M. Alcide d'Orbigny.
1848. { Cape-of-Good-Hope Fossils. / M. Alcide d'Orbigny. }
1849. Mr. William Lonsdale.
1850. Prof. John Morris.
1851. M. Joachim Barrande.
1852. Prof. John Morris.
1853. Prof. L. G. de Koninck.
1854. Dr. S. P. Woodward.
1855. Drs. G. and F. Sandberger.
1856. Prof. G. P. Deshayes.
1857. Dr. S. P. Woodward.
1858. Prof. James Hall.
1859. Mr. Charles Peach.
1860. { Prof. T. Rupert Jones. / Mr. W. K. Parker. }
1861. Prof. Auguste Daubrée.
1862. Prof. Oswald Heer.
1863. Prof. Ferdinand Senft.
1864. Prof. G. P. Deshayes.
1865. Mr. J. W. Salter.
1866. Dr. Henry Woodward.
1867. Mr. W. H. Baily.
1868. M. J. Bosquet.
1869. Mr. William Carruthers.
1870. M. Marie Rouault.
1871. Mr. Robert Etheridge.
1872. Dr. James Croll.
1873. Prof. John W. Judd.
1874. Dr. Henri Nyst.
1875. Prof. L. C. Miall.
1876. Prof. Giuseppe Seguenza.
1877. Mr. R. Etheridge, Jun.
1878. Prof. William J. Sollas.
1879. Mr. Samuel Allport.
1880. Mr. Thomas Davies.
1881. Dr. Ramsay H. Traquair.
1882. Dr. George J. Hinde.
1883. Prof. John Milne.
1884. Mr. E. Tulley Newton.
1885. Dr. Charles Callaway.
1886. Mr. J. Starkie Gardner.
1887. Mr. Benjamin N. Peach.
1888. Mr. John Horne.
1889. Dr. A. Smith Woodward.
1890. Mr. W. A. E. Ussher.
1891. Mr. Richard Lydekker.
1892. Mr. Orville A. Derby.
1893. Mr. John G. Goodchild.
1894. Mr. Aubrey Strahan.
1895. Prof. W. W. Watts.
1896. Mr. Alfred Harker.
1897. Dr. Francis A. Bather.
1898. Prof. E. J. Garwood.
1899. Prof. J. B. Harrison.
1900. Mr. George T. Prior.
1901. Mr. Arthur W. Rowe.

AWARDS OF THE MURCHISON MEDAL

UNDER THE CONDITIONS OF THE

'MURCHISON GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL OF THE LATE

SIR RODERICK IMPEY MURCHISON, Bart., F.R.S., F.G.S.

'To be applied in every consecutive year in such manner as the Council of the Society may deem most useful in advancing Geological Science, whether by granting sums of money to travellers in pursuit of knowledge, to authors of memoirs, or to persons actually employed in any enquiries bearing upon the science of Geology, or in rewarding any such travellers, authors, or other persons, and the Medal to be given to some person to whom such Council shall grant any sum of money or recompense in respect of Geological Science.'

1873. Mr. William Davies.
1874. Dr. J. J. Bigsby.
1875. Mr. W. J. Henwood.
1876. Mr. Alfred R. C. Selwyn.
1877. Rev. W. B. Clarke.
1878. Prof. Hanns B. Geinitz.
1879. Sir Frederick M'Coy.
1880. Mr. Robert Etheridge.
1881. Sir Archibald Geikie.
1882. Prof. Jules Gosselet.
1883. Prof. H. R. Gœppert.
1884. Dr. Henry Woodward.
1885. Dr. Ferdinand von Rœmer.
1886. Mr. William Whitaker.
1887. Rev. Peter B. Brodie.
1888. Prof. J. S. Newberry.
1889. Prof. James Geikie.
1890. Prof. Edward Hull.
1891. Prof. W. C. Brögger.
1892. Prof. A. H. Green.
1893. Rev. Osmond Fisher.
1894. Mr. W. T. Aveline.
1895. Prof. Gustav Lindström.
1896. Mr. T. Mellard Reade.
1897. Mr. Horace B. Woodward.
1898. Mr. T. F. Jamieson.
1899. Mr. Benjamin N. Peach. Mr. John Horne.
1900. Baron A. E. Nordenskiöld.
1901. Mr. A. J. Jukes-Browne.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'MURCHISON GEOLOGICAL FUND.'

1873. Prof. Oswald Heer.
1874. Mr. Alfred Bell.
1874. Prof. Ralph Tate.
1875. Prof. H. G. Seeley.
1876. Dr. James Croll.
1877. Rev. J. F. Blake.
1878. Prof. Charles Lapworth.
1879. Mr. J. W. Kirkby.
1880. Mr. Robert Etheridge.
1881. Mr. Frank Rutley.
1882. Prof. T. Rupert Jones.
1883. Dr. John Young.
1884. Mr. Martin Simpson.
1885. Mr. Horace B. Woodward.
1886. Mr. Clement Reid.
1887. Mr. Robert Kidston.
1888. Mr. Edward Wilson.
1889. Prof. Grenville A. J. Cole.
1890. Mr. Edward Wethered.
1891. Rev. Richard Baron.
1892. Mr. Beeby Thompson.
1893. Mr. G. J. Williams.
1894. Mr. George Barrow.
1895. Mr. Albert C. Seward.
1896. Mr. Philip Lake.
1897. Mr. S. S. Buckman.
1898. Miss Jane Donald.
1899. Mr. James Bennie.
1900. Mr. A. Vaughan Jennings.
1901. Mr. Thomas S. Hall.

AWARDS OF THE LYELL MEDAL

UNDER THE CONDITIONS OF THE

'LYELL GEOLOGICAL FUND,'

ESTABLISHED UNDER THE WILL AND CODICIL OF THE LATE

SIR CHARLES LYELL, BART., F.R.S., F.G.S.

The Medal 'to be given annually' (or from time to time) 'as a mark of honorary distinction and as an expression on the part of the governing body of the Society that the Medallist (who may be of any country or either sex) has deserved well of the Science,'—'not less than one third of the annual interest [of the fund] to accompany the Medal, the remaining interest to be given in one or more portions at the discretion of the Council for the encouragement of Geology or of any of the allied sciences by which they shall consider Geology to have been most materially advanced, either for travelling expenses or for a memoir or paper published, or in progress, and without reference to the sex or nationality of the author, or the language in which any such memoir or paper may be written.'

1876. Prof. John Morris.
1877. Sir James Hector.
1878. Mr. George Busk.
1879. Prof. Edmond Hébert.
1880. Sir John Evans.
1881. Sir J. William Dawson.
1882. Dr. J. Lycett.
1883. Dr. W. B. Carpenter.
1884. Dr. Joseph Leidy.
1885. Prof. H. G. Seeley.
1886. Mr. William Pengelly.
1887. Mr. Samuel Allport.
1888. Prof. H. A. Nicholson.
1889. Prof. W. Boyd Dawkins.
1890. Prof. T. Rupert Jones.
1891. Prof. T. McKenny Hughes.
1892. Mr. George H. Morton.
1893. Mr. E. Tulley Newton.
1894. Prof. John Milne.
1895. Rev. J. F. Blake.
1896. Dr. A. Smith Woodward.
1897. Dr. George J. Hinde.
1898. Prof. Wilhelm Waagen.
1899. Lt.-Gen. C. A. McMahon.
1900. Mr. John Edward Marr.
1901. Dr. Ramsay H. Traquair.

AWARDS

OF THE

BALANCE OF THE PROCEEDS OF THE 'LYELL GEOLOGICAL FUND.'

1876. Prof. John Morris.
1877. Mr. William Pengelly.
1878. Prof. Wilhelm Waagen.
1879. Prof. H. A. Nicholson.
1879. Dr. Henry Woodward.
1880. Prof. F. A. von Quenstedt.
1881. Prof. Anton Fritsch.
1881. Mr. G. R. Vine.
1882. Rev. Norman Glass.
1882. Prof. Charles Lapworth.
1883. Mr. P. H. Carpenter.
1883. M. Ed. Rigaux.
1884. Prof. Charles Lapworth.
1885. Mr. A. J. Jukes-Browne.
1886. Mr. D. Mackintosh.
1887. Rev. Osmond Fisher.
1888. Mr. Arthur H. Foord.
1888. Mr. Thomas Roberts.
1889. M. Louis Dollo.
1890. Mr. C. Davies Sherborn.
1891. Dr. C. I. Forsyth-Major.
1891. Mr. George W. Lamplugh.
1892. Prof. J. W. Gregory.
1892. Mr. Edwin A. Walford.
1893. Miss Catherine A. Raisin.
1893. Mr. Alfred N. Leeds.
1894. Mr. William Hill.
1895. Mr. Percy F. Kendall.
1895. Mr. Benjamin Harrison.
1896. Dr. William F. Hume.
1896. Dr. Charles W. Andrews.
1897. Mr. W. J. Lewis Abbott.
1897. Mr. Joseph Lomas.
1898. Mr. William H. Shrubsole.
1898. Mr. Henry Woods.
1899. Mr. Frederick Chapman.
1899. Mr. John Ward.
1900. Miss Gertrude L. Elles.
1901. Dr. John W. Evans.
1901. Mr. Alexander McHenry.

AWARDS OF THE BIGSBY MEDAL,

FOUNDED BY THE LATE

DR. J. J. BIGSBY, F.R.S., F.G.S.

To be awarded biennially 'as an acknowledgement of eminent services in any department of Geology, irrespective of the receiver's country; but he must not be older than 45 years at his last birthday, thus probably not too old for further work, and not too young to have done much.'

1877. Prof. Othniel C. Marsh.
1879. Prof. Edward D. Cope.
1881. Prof. Charles Barrois.
1883. Dr. Henry Hicks.
1885. Prof. Alphonse Renard.
1887. Prof. Charles Lapworth.
1889. Mr. J. J. Harris Teall.
1891. Dr. George M. Dawson.
1893. Prof. William J. Sollas.
1895. Mr. Charles D. Walcott.
1897. Mr. Clement Reid.
1899. Prof. T. W. Edgeworth David.
1901. Mr. George W. Lamplugh.

AWARDS OF THE PROCEEDS OF THE BARLOW-JAMESON FUND,

ESTABLISHED UNDER THE WILL OF THE LATE

DR. H. C. BARLOW, F.G.S.

'The perpetual interest to be applied every two or three years, as may be approved by the Council, to or for the advancement of Geological Science.'

1879. Purchase of Microscope.
1881. Purchase of Microscope-lamps.
1882. Baron C. von Ettingshausen.
1884. Dr. James Croll.
1884. Prof. Leo Lesquereux.
1886. Dr. H. J. Johnston-Lavis.
1888. Museum.
1890. Mr. W. Jerome Harrison.
1892. Prof. Charles Mayer-Eymar.
1893. Purchase of Scientific Instruments for Capt. F. E. Younghusband.
1894. Dr. Charles Davison.
1896. Mr. Joseph Wright.
1896. Mr. John Storrie.
1898. Mr. Edward Greenly.
1900. Mr. George C. Crick.
1900. Prof. Theodore T. Groom.

Estimates for

INCOME EXPECTED.

	£	s.	d.	£	s.	d.
Compositions				90	0	0
Due for Arrears of Admission Fees	119	14	0			
Admission Fees, 1901	207	18	0			
				327	12	0
Arrears of Annual Contributions	168	0	0			
Annual Contributions, 1901, from Resident Fellows and Non-Residents	1700	0	0			
Annual Contributions in advance	45	0	0			
				1913	0	0
Sale of Quarterly Journal, including Longmans's Account	......			150	0	0
Sale of Transactions, Library Catalogue, General Index, Hutton's 'Theory of the Earth' vol. iii, Hochstetter's 'New Zealand,' and List of Fellows	......			5	0	0
Dividends on £2500 India 3 per cent. Stock	75	0	0			
Dividends on £300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	15	0	0			
Dividends on £2250 London & North-Western Railway 4 per cent. Preference Stock	90	0	0			
Dividends on £2800 London & South-Western Railway 4 per cent. Preference Stock	112	0	0			
Dividends on £2072 Midland Railway 2½ per cent. Perpetual Preference Stock	51	16	0			
				343	16	0
				2829	8	0
Balance against the Society				467	5	0
				£3296	13	0

Note.—The following Funds are available for Extraordinary Expenditure:—

	£	s.	d.
Balance in the Bankers' hands at December 31st, 1900:			
On Current Account	122	17	2
On Deposit Account	250	0	0
Balance in the Clerk's hands at December 31st, 1900	15	17	8
	£388	14	10

the Year 1901.

EXPENDITURE ESTIMATED.

	£	s.	d.	£	s.	d.
House Expenditure:						
Taxes		15	0			
Fire Insurance	15	0	0			
Electric Lighting	40	0	0			
Gas	8	0	0			
Fuel	35	0	0			
Furniture and Repairs	30	0	0			
House-repairs and Maintenance	30	0	0			
Annual Cleaning	15	0	0			
Washing and Sundries	35	0	0			
Tea at Meetings	20	0	0			
				228	15	0
Salaries and Wages, etc.:						
Assistant Secretary	350	0	0			
„ Half Premium of Life Insurance	10	15	0			
Assistant Librarian	150	0	0			
Assistant Clerk	115	0	0			
House Porter and Upper Housemaid	91	12	0			
Under Housemaid	47	12	0			
Office Boy	31	4	0			
Charwoman and Occasional Assistance	10	0	0			
Accountant's Fee	10	10	0			
				816	13	0
Office Expenditure:						
Stationery	35	0	0			
Miscellaneous Printing	45	0	0			
Postage and Sundry Expenses	85	0	0			
				165	0	0
Library (Books and Binding)				230	0	0
International Catalogue of Scientific Literature				60	0	0
Museum				5	0	0
Publications:						
Quarterly Journal, including Commission on Sale	900	0	0			
Record of Geological Literature	130	0	0			
List of Fellows	35	0	0			
Postage on Journal, Addressing, etc.	90	0	0			
Abstracts, including Postage	110	0	0			
				1265	0	0
Estimate of Ordinary Expenditure				2770	8	0
Cost of Redecoration of the Society's Apartments				500	0	0
Electric-Light Installation				26	5	0
				£3296	13	0

W. T. BLANFORD, *Treasurer.*

January 26th, 1901.

Income and Expenditure during the

RECEIPTS.

	£	s.	d.	£	s.	d.
To Balance in hands of Bankers at January 1st, 1900:						
On Current Account	146	5	10			
On Deposit Account	250	0	0			
,, Balance in hands of Clerk at January 1st, 1900	24	8	0			
				420	13	10
,, Compositions				103	0	0
,, Admission Fees:						
Arrears	44	2	0			
Current	245	14	0			
				289	16	0
,, Arrears of Annual Contributions	169	2	0			
,, Annual Contributions of 1900, namely:						
Resident Fellows	1693	13	0			
Non-Resident Fellows	6	6	0			
,, Annual Contributions in advance	54	12	0			
				1923	13	0
,, Publications:						
Sale of Journals, Vols. i to lv *	102	0	6			
,, Journal, Vol. lvi *	47	19	0			
,, Geological Map	2	9	6			
,, Record of Geological Literature ...	1	1	6			
,, Library Catalogue	1	1	0			
,, List of Fellows		4	0			
,, General Index to Quarterly Journal, vols. i to l		15	6			
,, Hutton's 'Theory of the Earth' vol. iii		16	9			
,, Hochstetter's 'New Zealand'		6	0			
				156	13	9
,, Income Tax Repayment				11	12	0
,, Dividends (less Income Tax) on						
£2500 India 3 per cent. Stock ..	71	17	6			
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	14	8	9			
£2250 London & North-Western Railway 4 per cent. Preference Stock	86	12	6			
£2800 London & South-Western Railway 4 per cent. Preference Stock	107	16	0			
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	49	17	2			
				330	11	11
,, Interest on Deposit				14	12	7
,, Amount refunded by H.M. Office of Works for alterations to Lavatory				200	0	0
				£3450	13	1

* Due from Messrs. Longmans, in addition to the above, on Journal, Vol. lvi, etc. £85 1 0

Year ended December 31st, 1900.

PAYMENTS.

	£	s.	d.	£	s.	d.
By House Expenditure:						
Taxes		15	0			
Fire Insurance	15	0	0			
Electric Lighting	16	15	4			
Legacy Duty on Prestwich Bequest of Books	1	0	0			
Gas	24	19	0			
Fuel	35	10	6			
Furniture and Repairs	29	8	6			
House-repairs and Maintenance	25	15	6			
Annual Cleaning	12	14	6			
Washing and Sundries	33	16	10			
Tea at Meetings	20	10	11			
				216	6	1
„ **Salaries and Wages, etc.:**						
Assistant Secretary	325	0	0			
„ Half Premium of Life Insurance	10	15	0			
Assistant Librarian	150	0	0			
Assistant Clerk	110	0	0			
Assistant Clerk: Allowance for Rooms during alterations	5	5	0			
House Porter and Upper Housemaid	91	17	6			
Under Housemaid	43	8	8			
Office Boy	30	15	0			
Charwoman and Occasional Assistance	24	2	0			
Accountant's Fee	10	10	0			
				801	13	2
„ **Office Expenditure:**						
Stationery	34	4	6			
Miscellaneous Printing	44	5	0			
Postage and Sundry Expenses	83	2	5			
				161	11	11
„ **Library**				213	19	3
„ **Publications:**						
Journal, Vols. i to lv, Commission on sale thereof	9	0	1			
Journal, Vol. lvi, Commission on sale thereof	3	1	6			
Paper, Printing, and Illustrations	986	16	10			
List of Fellows	36	10	0			
Record of Geological Literature	122	4	10			
Postage on Journal, Addressing, etc.	97	16	3			
Abstracts, including Postage	111	12	0			
				1367	1	6
„ **Electric-Light Installation**				301	6	4
„ **Balance in hands of Bankers at December 31st, 1900:**						
On Current Account	122	17	2			
On Deposit Account	250	0	0			
„ **Balance in hands of Clerk**	15	17	8			
				388	14	10
				£3450	13	1

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

HORACE W. MONCKTON, F. G. HILTON PRICE, } *Auditors.*

W. T. BLANFORD, *Treasurer.*

January 26th, 1901.

Statement of Trust Funds: December 31st, 1900.

'Wollaston Donation Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1900	32	3	8	By Cost of striking Gold Medal awarded to Prof. Grove Karl Gilbert	10	10	0
" Dividends (less Income Tax) on the Fund invested in £1073 Hampshire County 3 per cent. Stock	30	16	11	" Award to Mr. George Thurland Prior	21	13	8
" Repayment of one year's Income Tax	1	1	4	" Balance at the Bankers' at December 31st, 1900	31	18	3
	£64	1	11		£64	1	11

'Murchison Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1900	20	13	6	By Award to Baron Adolf Erik Nordenskiöld, and Medal.	10	10	0
" Dividends (less Income Tax) on the Fund invested in £1334 London & North-Western Railway 3 per cent. Debenture Stock	38	10	4	" " Mr. Alfred Vaughan Jennings	28	13	4
" Repayment of one year's Income Tax	1	6	8	" Cost of Medal		17	0
				" Balance at the Bankers' at December 31st, 1900	20	10	2
	£60	10	6		£60	10	6

'Lyell Geological Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1900	53	6	11	By Award to Mr. John Edward Marr, and Medal	50	0	0
" Dividends (less Income Tax) on the Fund invested in £2010 1*s.* 0*d.* Metropolitan $3\frac{1}{2}$ per cent. Stock	67	8	6	" " Miss Gertrude L. Elles	19	6	0
" Repayment of one year's Income Tax	2	6	8	" Cost of Medal	1	1	0
				" Balance at the Bankers' at December 31st, 1900	52	15	1
	£123	2	1		£123	2	1

'Barlow-Jameson Fund.' Trust Account.

Receipts.	£	s.	d.	Payments.	£	s.	d.
To Balance at the Bankers' at January 1st, 1900	38	9	8	By Award to Mr. George C. Crick	21	0	0
" Dividends (less Income Tax) on the Fund invested in £468 Great Northern Railway 3 per cent. Debenture Stock	13	10	4	" " Prof. Theodore Thomas Groom	21	0	0
" Repayment of one year's Income Tax		9	4	" " Miss Gertrude L. Elles	1	14	0
				" Balance at the Bankers' at December 31st, 1900	8	15	4
	£52	9	4		£52	9	4

‘Bigsby Fund.’ Trust Account.

Receipts.	£	s.	d.
To Balance at the Bankers' at January 1st, 1900	3	5	1
„ Dividends (less Income Tax) on the Fund invested in £210 Cardiff 3 per cent. Stock	6	0	9
„ Repayment of one year's Income Tax		4	2
	£9	10	0

Payments.	£	s.	d.
By Balance at the Bankers' at December 31st, 1900	9	10	0
	£9	10	0

‘Geological Relief Fund.’ Trust Account.

Receipts.	£	s.	d.
To Balance at the Bankers' at January 1st, 1900	5	18	10
„ Dividends (less Income Tax) on the Fund invested in £139 3*s*. 7*d*. India 3 per cent. Stock	4	0	0
„ Repayment of one year's Income Tax		2	9
	£10	1	7

Payments.	£	s.	d.
By Balance at the Bankers' at December 31st, 1900	10	1	7
	£10	1	7

‘Prestwich Trust Fund.’ Trust Account.

Receipts.	£	s.	d.
To Cash received of Flower & Flower, in payment of Legacy of £800, less Abatement and Legacy Duty	616	14	3
„ Geological Society, for Legacy Duty on bequest of Books	1	0	0
„ Dividends (less Income Tax) on the Fund invested in £591 1*s*. 4*d*. India 3 per cent. Stock	12	14	3
	£630	8	6

Payments.	£	s.	d.
By Purchase of £591 1*s*. 4*d*. India 3 per cent. Stock at 104⅜	617	14	3
„ Balance at the Bankers' at December 31st, 1900	12	14	3
	£630	8	6

We have compared this Statement with the Books and Accounts presented to us, and find them to agree.

W. T. BLANFORD, *Treasurer*.

January 26th, 1901.

HORACE W. MONCKTON,
F. G. HILTON PRICE, } *Auditors*.

Statement of the Society's Property: December 31st, 1900.

PROPERTY.	£	s.	d.		£	s.	d.
… from Longmans & Co., on account of Journal, …ol. LVI, etc.	85	1	0	Balance in favour of the Society	12,244	8	7
…ance in the Bankers' hands, December 31st, 1900:							
On Current Account	122	17	2				
On Deposit Account	250	0	0				
…ance in the Clerk's hands, December 31st, 1900	15	17	8				
…unded Property:—							
£2500 India 3 per cent. Stock	2623	6	0				
£2250 London & North-Western Railway 4 per cent. Preference Stock	2898	10	6				
£2800 London & South-Western Railway 4 per cent. Preference Stock	3607	7	6				
£300 London, Brighton, & South Coast Railway 5 per cent. Consolidated Preference Stock	502	15	3				
£2072 Midland Railway 2½ per cent. Perpetual Preference Stock	1850	19	6				
Arrears of Admission Fees	119	14	0				
Arrears of Annual Contributions	168	0	0				
	£12,244	8	7		£12,244	8	7

[*N.B.—The above does not include the value of the Collections, Library, Furniture, and Stock of unsold Publications.*]

W. T. BLANFORD, *Treasurer.*

January 26th, 1901.

Note.—The investments in Stocks are valued at their cost price.

Award of the Wollaston Medal.

In handing the Wollaston Medal, awarded to Prof. Charles Barrois, F.M.G.S., of Lille, to Sir Archibald Geikie, for transmission to the recipient, the President addressed him as follows:—

Sir Archibald Geikie,—

In these days of specialization few men are endowed with those faculties which enable them to contribute with marked ability to all branches of our many-sided science; but among those few Prof. Barrois must unquestionably be ranked.

In the Monograph on the Calcaire d'Erbray and many other papers he has established his reputation as a palæontologist; in numerous memoirs on the Granitic and Metamorphic Rocks of Britanny he figures as an accomplished petrologist; while in the many geological maps of the same district he has constructed a lasting monument to his skill and energy as a geological surveyor.

His published work represents a vast accumulation of facts carefully observed, clearly described, and lucidly arranged. More than this, it is often full of suggestiveness. He has had the satisfaction of initiating lines of research which have been followed up with great success by others.

It was he who first taught us how to zone our English Chalk by the aid of the fossils which it contains, and the friendships which he formed during the progress of that work have been strengthened by the lapse of time. He might repeat with truth the words of another visitor to these Islands from the other side of the Channel: *veni, vidi, vici.*

In his recent publications on Britanny he has correlated the breadth and character of the metamorphic zones surrounding the granitic masses with the thickness of the cover under which the intrusions took place, and has suggested ideas that may prove of great importance in connexion with such questions as the origin of the crystalline schists and igneous magmas.

But he has aided the progress of geology in other ways than as an original worker. The illustrious pupil of an illustrious master, he has contributed to maintain the great reputation of Lille as a centre of geological teaching; while his extensive knowledge and exceptional organizing ability have ever been at the disposal of the International Geological Congress and kindred associations.

Many years have elapsed since I had the privilege of making his

acquaintance, and it is, therefore, with the greatest pleasure that I now ask you to transmit to him the Wollaston Medal, which has been awarded to him by the Council as a mark of their appreciation of the great services that he has rendered to all branches of geological science.

Sir ARCHIBALD GEIKIE replied in the following words:—

MR. PRESIDENT,—

It has been to my friend Prof. Barrois a matter of very keen regret that he is prevented from being here to-day, to renew his personal relations with the Fellows of the Geological Society, and to receive from them the highest distinction which it is in their power to bestow. We must all deeply sympathize with him in the causes that deprive us of his presence. Bowed down by one of the greatest afflictions that can befall a father—the death of a son in the full bloom and promise of early manhood—he has manfully struggled with his numerous duties, until at last his health has given way under the strain. Let us hope that he may soon be restored to his former vigour, and be able to resume the researches in Britanny and the detailed description of them on which he has so long been engaged. He has asked me to receive this Medal for him, and I count it a great privilege and honour to be the intermediary between the Geological Society of London and one of the most distinguished and widely esteemed geologists of Europe. Prof. Barrois has sent a letter of thanks, which I will now read:—

'MR. PRESIDENT,—

'Allow me to express my gratitude for the new honour which the Geological Society has bestowed upon me, by the award of the Wollaston Medal, as I cannot but recall that the Council has on a former occasion encouraged me in my scientific work by the award of the Bigsby Medal.

'I have since made long wanderings along the Channel cliffs on both sides, from Chalk to granite, for the sake of science, in the steps of De la Beche, Fitton, Godwin-Austen, and the founders of stratigraphical geology; and it is for me a very unexpected event to see my name written to-day, for ever, with theirs, in the Proceedings of the Society.

'No distinction can be more gratifying to a geologist than to receive its highest award from the Council of the illustrious Society which for nearly a century has extended our knowledge in every branch of geology, and promoted progress in every part of the earth. I so greatly appreciate this great honour, that I feel as if the work that I have been able to accomplish was too small to merit the Wollaston Medal, granted as a reward, but rather as a friendly incitation to go on in my labour—"upward and onward."'

'Lille, February 9th, 1901. 'CHARLES BARROIS.'

Award of the Wollaston Donation Fund.

The President then presented the Balance of the Proceeds of the Wollaston Donation Fund to Mr. Arthur Walton Rowe, M.B., M.S., of Margate, addressing him as follows:—

Dr. Rowe,—

It will, I am sure, be a source of gratification to you to be associated with Prof. Barrois on the present occasion, for you have done much to confirm and extend the principles which he first applied to the elucidation of the structure of the English Chalk. We recognize, however, that, although your work has been of very great stratigraphical importance, your main object is biological, and that the task you have set yourself is that of working out the evolution of organic forms during the Upper Cretaceous Period.

In your paper on *Micraster* you have set an example which I trust will be followed. You have shown how it is possible to deal with a vast mass of material, so as to bring out the main facts of evolution, without burdening science with hosts of new names and long lists of synonyms.

By the application of the dental engine to the preparation, and of microphotography to the illustration, of fossils, you have also rendered signal service to science.

The Council of the Geological Society, in making this Award, have been desirous of expressing their gratitude to you for the work that you have already accomplished, and their lively sense of favours to come.

Award of the Murchison Medal.

In handing the Murchison Medal, awarded to Mr. Alfred John Jukes-Browne, B.A., of H.M. Geological Survey, to Mr. W. Whitaker for transmission to the recipient, the President addressed him as follows:—

Mr. Whitaker,—

Mr. Jukes-Browne, whose absence we all deeply regret, has aided the progress of geology in many ways. His numerous writings on the Upper Cretaceous Rocks are too well known to

make it necessary for me to refer to them in detail. He has, from the first, recognized the enormous importance of associating palæontological with stratigraphical work, and by original research, as well as by a critical study of the writings of others, has made himself master of the geology of that period to which he has especially devoted himself.

But he possesses also a good all-round knowledge of geology. His Handbooks on Physical and Historical Geology have been of great service to students, and his suggestive work on the Building of the British Isles has been the means of directing attention to many problems of considerable theoretical interest.

There is yet another way in which he has rendered great service to geology, and that is as a stimulator of work in others. I am sure that no one will be more ready to acknowledge this than Mr. William Hill, with whom Mr. Jukes-Browne has been so long associated.

In recognition of these many services to our science, the Council have awarded to him the Murchison Medal, which I, an old College friend and fellow-student, now ask you to transmit to him with our heartiest good wishes.

Mr. Whitaker, having expressed his gratification at the privilege of receiving the Medal on behalf of an old colleague and valued friend, read the following extracts from a letter which he had received from Mr. Jukes-Browne:—

'I beg you to convey to the Council of the Geological Society my deep appreciation of the honour conferred upon me by the award of the Murchison Medal, and my great regret that the state of my health makes it impossible for me to be present in person to express my acknowledgments.

'That such work as I have been able to accomplish should be thought worthy of this high reward is not only a present gratification, but will be an incentive to show myself more worthy of such recognition. I feel also that I have been specially fortunate in my friends, and that without the assistance of two of them in particular—Mr. W. Hill and Prof. J. B. Harrison—many of the investigations in which I have been concerned would have been incomplete.

'I should like further to say that the pleasure of receiving the Murchison Medal on the present occasion is much enhanced by the knowledge that the Wollaston Medal is at the same time awarded to my old friend, Prof. Barrois, whose zonal work among the Cretaceous Rocks of England and France has added so much to our knowledge of those rocks.'

Award of the Murchison Geological Fund.

The President then handed the Balance of the Proceeds of the Murchison Geological Fund, awarded to Mr. Thomas Sargeant Hall, M.A., of Melbourne, to Prof. J. W. Judd, for transmission to the recipient, addressing him as follows:—

Professor Judd,—

In awarding the Balance of the Proceeds of the Murchison Fund to Mr. Hall, the Council is desirous of recognizing the value of his many contributions to Australian geology, and especially of his detailed researches on the Zonal Distribution of the Graptolites of Victoria. His work has thrown much light on the Lower Palæozoic history of Australia; while his discovery of the coincidence of the Ordovician auriferous belts with certain graptolitic zones is an illustration of the bearing of palæontological research on economic questions.

His application of the zonal method of research to the Kainozoic deposits of Victoria has done much to elucidate the later geological history of the Colony, and his bibliographic labours have, I am told, greatly facilitated the work of his scientific colleagues in Victoria. We hope that this Award will be of some assistance to him in further researches.

Award of the Lyell Medal.

In presenting the Lyell Medal to Ramsay Heatley Traquair, M.D., F.R.S., of Edinburgh, the President addressed him in the following words:—

Dr. Traquair,—

The Council of the Geological Society, in presenting you with the Lyell Medal, desires to express its sense of the great value of your many contributions to palæontology. More than thirty years have elapsed since the publication of your first papers on Fossil Fishes, and during the whole of that period you have been giving evidence of your keen insight into the structure of these interesting forms of life. I can only refer to one or two of your more important works.

Your memoirs on the structure of the Palæoniscidæ and Platysomidæ are, I believe, masterpieces of descriptive palæontology, and must for ever remain most valuable works of reference. Of great importance, from a geological point of view, have been your researches

bearing on the Fish-Fauna of the Old Red Sandstone of Scotland. You have not only shown the complete divergence between the fauna of the Orcadian Series and that of the Lower Old Red Sandstone south of the Grampians, but you have also pointed out that in certain areas the fishes in different divisions of that formation are arranged in life-zones—a fact which has been of service to the field-geologist.

Your last, and perhaps your greatest, work is your monograph on the remarkable Fossil Fishes from the Silurian Rocks of the South of Scotland. Your keen insight and wide knowledge of fossil ichthyology enabled you to show, among other points, that the group of the Heterostraci, which hitherto contained only the Pteraspidæ, must be considerably enlarged, and that a transition could be seen from the shagreen-covered Cœlolepidæ to the plate-covered Pteraspidæ. You have also arrived at the conclusion that the Heterostraci, though not actual Selachians, had in all probability a common origin with the primitive Elasmobranchs. These results must be of the highest interest to biologists.

I have great pleasure in handing to you the Medal, together with our best wishes that you may long be spared to carry on your most valuable researches.

Dr. Traquair replied as follows:—

Mr. President,—

Permit me to thank the Council of the Geological Society for the honour which they have this day conferred upon me, and you, Sir, for the kind words which you have spoken regarding my work.

I am much gratified to hear that some of that work has been of use to the stratigraphical geologist, as it is indeed impossible for the palæontologist who has himself collected in the field, to avoid taking an interest in his subject from the geological standpoint also.

The impulse, however, which led me to take up Fossil Fishes as a speciality was entirely biological. While still a boy at school I broke open an ironstone-nodule containing a piece of a Palæoniscid fish, and was thereupon seized by an intense curiosity to know how the bones of its head were arranged. As I did not find the information that I desired in the books, I resolved some day to try and work out the problem myself. Need I remark that, when in due time I got fairly to work on the subject, I found that fossil ichthyology presented a field sufficient to supply not only myself, but many others, with original work for our lifetimes?

If the work that I have accomplished in this field falls far short of the realization of early dreams, it is still gratifying for me to find that I have been able to do enough to merit this expression of the Society's approbation.

Awards from the Lyell Geological Fund.

In presenting one half of the Balance of the Proceeds of the Lyell Geological Fund to John William Evans, D.Sc., LL.B., the President addressed him as follows:—

Dr. Evans,—

Half the Balance of the Proceeds of the Lyell Fund has been awarded to you, in recognition of the importance of your geological work during the last ten years. Your visit to an almost unknown part of Brazil, and several years' residence in India, have enabled you to make observations and to collect specimens of great value to our science. The papers which you have already published in our Journal on the Matto Grosso District, and on the Calcareous Sandstones and Monchiquites of North-western India, are evidence of your capacity for original work.

We trust that this Award may aid you in publishing the results of investigations that you are known to have carried out while engaged in the Survey of the State of Junagarh (Kathiawar), and will encourage you in further work.

In handing the other half of the Balance of the Proceeds of the Lyell Geological Fund, awarded to Mr. Alexander McHenry, of the Geological Survey of Ireland, to Sir Archibald Geikie for transmission to the recipient, the President addressed him in the following words:—

Sir Archibald Geikie,—

Mr. McHenry's claims to recognition are well known to you, and the fact that you receive the Award of a moiety of the Balance of the Proceeds of the Lyell Geological Fund on his behalf, is a proof that you cordially endorse the action of the Council. For forty years he has laboured to advance our knowledge of Irish Geology as a member of the Geological Survey; first as a collector of fossils and rock-specimens, and afterwards as a member of the Surveying Staff. Most of his work has been published in the Maps and Memoirs of

the Geological Survey, to which he has devoted himself, as you yourself have said, with admirable loyalty and enthusiasm. One of his most useful labours has been the preparation, in conjunction with his former colleague, Prof. Watts, of a Guide to the Collection of Rocks and Fossils belonging to the Geological Survey of Ireland. His extensive and accurate knowledge largely contributed to make this work a most valuable compendium of Irish Geology. We hope that this Award will act as an encouragement to him, and be of some assistance in further work.

Sir Archibald Geikie, in reply, said:—

Mr. President,—

On the part of my old colleague, I have to express to the Geological Society his best thanks for the recognition of his work which is expressed in this Award. Next to myself he is the member of the Geological Survey who has been longest on the staff. His whole life has been devoted to his official duties, and he has only now and then ventured to make his appearance in non-official print. His labours are thus chronicled in the Maps, Sections, and Memoirs of the Geological Survey of Ireland, and are probably familiar to comparatively few geologists. He has been content honestly and strenuously to do his duty, with a loyalty that has never flinched, and with an enthusiasm that seems to wax higher as the years go past. To such a man you may well believe that recognition from the Geological Society is as precious as it is unlooked for. It will nerve him with fresh energy for the task of revision of the Superficial Deposits of Ireland on which the Survey is about to enter; for it will show him that his work is not only known to his colleagues, but is appreciated by the leaders of geological science here.

Award of the Bigsby Medal.

In presenting the Bigsby Medal to Mr. George William Lamplugh, of H.M. Geological Survey, the President addressed him as follows:—

Mr. Lamplugh,—

In 1891 the Council of the Geological Society recognized the value of your work on the Glacial Deposits of Yorkshire and on the

Speeton Clay by an Award from the Lyell Fund. Since that time you have still further extended our knowledge of the Lower Cretaceous Rocks of Yorkshire and Lincolnshire, and have furnished Prof. Pavlov with material which has enabled him to throw considerable light on the physical conditions and migrations of the Cephalopod Fauna during the period represented by these rocks.

Your early work was done in the midst of an active and successful business career, which you gave up, somewhat against the advice of your friends, to join the Geological Survey and devote all your energy to the progress of science. Of late years you have been working in the Isle of Man, and the map of that island which you have produced is a striking proof of your skill as a geological surveyor. Its publication leads us to look forward with great expectations to the forthcoming memoir.

In awarding to you the Bigsby Medal, the Council feel that they are placing it in safe hands. You have done much, and they confidently expect that you will do more.

Mr. LAMPLUGH replied in the following words:—

Mr. PRESIDENT,—

It is not without a proper sense of responsibility that I receive this Medal. The terms of the Award leave no doubt that, while it is intended to some extent as a recognition of work already done, it is essentially intended as an incentive to further work, and implies a certain obligation in this respect—which you, Sir, in your encouraging words have not attempted to lighten. The recipients of this Medal in the past have always fulfilled the obligation, and it will indeed be a satisfaction to me if it be in my power to prove my fitness for the trust reposed in me by this Award.

You have made reference to my altered circumstances since the time, ten years ago, when my earlier work received kindly recognition from the Council of this Society; and it may, therefore, be permitted to me to confess that, in deciding to devote my whole energies to geological research, I felt some misgiving lest the studies which had proved so congenial as a recreation should take on another aspect when made the main occupation of my life. But the misgiving has proved groundless; the wider opportunity, so far from blunting my interest in these studies, has brought fresh zest, and on every side has opened up vistas of promising work for the future.

THE ANNIVERSARY ADDRESS OF THE PRESIDENT,

J. J. HARRIS TEALL, Esq., M.A., V.P.R.S.

The greatest loss that we have sustained during the past year is one which we share in common with the nation and the world. Our noble QUEEN VICTORIA, of ever-glorious memory, has passed away,

Robed in the simple splendour of her life.

As a Society we have to deplore the loss of a past-President, two Foreign Members, and many Fellows who have contributed to the progress of geology during the Victorian era, now, alas! for ever closed.

His Grace the late DUKE OF ARGYLL was too well-known in other spheres of activity to render it necessary that we should record the ordinary biographical details of his life in the pages of our Journal. Born in 1823, he was elected a Fellow of this Society in 1850, and in the following year communicated his classic paper on the Tertiary Leaf-beds in the Isle of Mull. The intercalation of the plant-bearing strata with the sheets of basaltic lava was clearly established in this communication, and thus a fact of vital importance in connection with the chronology of the volcanic eruptions of the Inner Hebrides was placed beyond dispute.

The clearness and accuracy with which the details of this occurrence are described and illustrated, by pen and pencil, make one regret that the numerous claims on his time by affairs of State and by the duties connected with the administration of a large domain, prevented him from following up a line of research for which he was obviously so well qualified.

His later communications were, for the most part, of a polemical character. He stood out boldly as a champion of the older faiths in opposition to the rapidly-growing ideas on such subjects as Glaciation, Earth-Sculpture, and Evolution; and it must be admitted that on many occasions his keen critical faculty, combined with his extensive knowledge, enabled him to find weak places in the armour of his opponents, while his literary skill and great eloquence often enabled him to drive home his attacks with striking effect.

The two addresses delivered during his presidency of this Society are illustrations of his attitude towards the tendency of geological thought at the time. He combated with great force the extreme

forms of the Glacial Theory, and many of his arguments find supporters at the present day—probably in this very room.

He has left his mark on the history of our age, and we are proud to think that, in the midst of a busy public life, he found time to carry out at least one original research of great importance, and kept up his general interest in our science till the end.

Alphonse Milne-Edwards, the renowned son of an illustrious father, Henri Milne-Edwards, was born at Paris in 1835, and died, after a brief illness, on April 21st, 1900. He, like so many celebrated zoologists, was trained for the medical profession, and took his degree in 1859. He became Assistant Naturalist at the Muséum d'Histoire Naturelle in 1862, and Professor at the School of Pharmacy in 1865. In 1876 he was appointed Professor of Zoology at the Muséum d'Histoire Naturelle, and in 1892 became Director of that institution, a post which he filled with great distinction until the time of his death.

Essentially a zoologist, and as such justly celebrated for his many labours among both vertebrate and invertebrate animals, he brought his wide knowledge to bear upon the problems of palæontology. In 1863 he published a paper on fossil birds:—'Mémoire sur la Distribution Géologique des Oiseaux Fossiles,' and his work on the Osteology of the Dodo appeared in 1866; but it was in 1867 that the first part of his great work appeared, 'Recherches Anatomiques & Paléontologiques pour servir à l'Histoire des Oiseaux Fossiles de la France,' which was completed in four folio volumes in 1871. This work is a monument of the labour and research of the writer, and still remains a classic of reference. He also wrote the 'History of the Birds of Madagascar,' in the great work published by A. Grandidier in 1876–85.

Alphonse Milne-Edwards became a Member of the French Academy of Sciences in 1879; and in 1884 he received the gold medal of the Geographical Society of France for his deep-sea explorations. He was elected a Foreign Member of the Zoological Society of London in 1876, a Foreign Correspondent of our own Geological Society in 1882, and a Foreign Member in 1899.

[E. T. N.]

Otto Martin Torell was born in Varberg (Sweden), on June 5th, 1828. At the age of 16 he entered as a student at Lund, where he took up the study of natural science, intending to become, like his

father, a physician. In 1858 he became *Med. Kand.*; but then devoted himself to zoological work, especially to the Geographical Distribution of the Lower Marine Animals. In this field Sven Lovén had already undertaken his epoch-making researches on the difference between present and past times, shown by the fossil fauna of the Bohusland shell-banks. These studies, carried on by Torell under Lovén's guidance, were the starting-point of his life's work. During a journey to Switzerland, made in 1856, he was struck by the resemblance of the Alpine moraines to the Drift of Sweden. Thenceforward Torell became a geologist. Combining enthusiasm with the technical knowledge of the true naturalist, he attacked the difficult problem of the Former Submergence of Scandinavia and of the neighbouring lands. At that time he accepted the popular idea of the diluvial origin of the Drift-deposits; but, on closer examination, he gave up this view, though satisfactory evidence was not easy to obtain.

It should not be forgotten that Lund, in Torell's student days, was deficient in collections, books, and geological instruction. Torell himself largely made up this deficiency. He saw that a true understanding of the bygone Glacial Period could only be gained through the study of the unexplored and still ice-clad Arctic regions. He therefore devoted the following years to this exploration, visiting Iceland in 1857, Spitsbergen (in company with Prof. Nordenskiöld) in 1858, and Greenland in 1859, thus commencing the long series of Swedish Arctic expeditions. His own latest and most important Arctic voyage was that undertaken, again in conjunction with Prof. Nordenskiöld, in 1861. To the cost of these expeditions he devoted a considerable part of the property inherited from his father.

Torell devoted the following years to Quaternary geology, gathering around him at Lund a band of enthusiastic disciples. In 1860 he had become *Adjunkt* in Zoology, and in 1866 Professor of Zoology and Geology. The value of his work, however, caused him to be appointed, in 1870, Chief of the Swedish Geological Survey, in this post following Axel Erdmann. On his transference to the capital he took the initiative in the foundation of the Geological Society of Stockholm. For over a quarter of a century, till 1897, he retained his official post, labouring both for science and for the practical application of geology to Swedish industries. He died on September 11th, 1900.

Both in England and in Germany Torell was well known and liked

for his enthusiasm and the ready courtesy with which he imparted his great store of experience. In Germany he showed that the Drift was mainly of glacial or fluvio-glacial origin, not marine, as had been thought. To England he made several visits, and pointed out how large a proportion of our East-coast Drift was probably of Scandinavian origin. He recognized various erratics found in Norfolk and Yorkshire as belonging to rocks peculiar to scattered islands in the Baltic, or to the neighbourhood of Christiania. Torell was not a ready writer, and his publications scarcely represent the work that he accomplished. This is to be measured rather by the commanding position which Scandinavia has taken in Arctic Exploration and in Glacial Geology. [C. R.]

JOHN ANSTIE, B.A., was an Associate Member of the Institute of Civil Engineers, and is best known to geologists by his work on 'The Coalfields of Gloucestershire & Somersetshire, & their Resources,' 1873. He gained his knowledge of these districts while working under the direction of Prestwich, who, as one of the members of the Royal Coal Commission, had been requested to report on the quantities of coal, wrought and unwrought, in the coalfields. Mr. Anstie prepared materials for some of the vertical and horizontal sections published by the Geological Survey, in illustration of the same coalfields.

He died on January 8th, 1900. [H. B. W.]

H. KIRBY ATKINSON, who joined the Society in 1886, was associated with the 'Colliery Guardian' for more than forty years, and had been for twenty-four years its Editor. He died on March 15th, 1900, aged 83.

GEORGE CLEMENTSON GREENWELL, M.Inst.C.E., became a Fellow of this Society in 1858. He was distinguished as a mining engineer, and his 'Practical Treatise on Mine Engineering,' of which the first edition was published in 1855, has always been regarded as a standard work.

Born at Newcastle-upon-Tyne on July 25th, 1821, he was educated partly in that city, and partly at the University of Edinburgh. In 1844 he commenced work among the collieries in County Durham, and in 1853 was appointed sole manager of the Countess Waldegrave's collieries at Radstock. Here he made a particular study of the Somerset Coal-Measures, concerning which

but little had been published since the famous paper by Buckland & Conybeare which appeared in our Transactions (1824). Mr. Greenwell's observations were printed in the Transactions of the North of England Institute of Mining Engineers, in those of the South Wales Institute of Engineers, and of the Manchester Geological Society. The most important of his works on the district was that published in conjunction with his friend, Mr. James McMurtrie, F.G.S., on 'The Radstock Portion of the Somersetshire Coalfield' (8vo, Newcastle-upon-Tyne, 1864). Leaving Radstock in 1863, Mr. Greenwell was occupied for some years in the management of collieries in Cheshire, until 1879, when he devoted himself entirely to consulting practice.

He died in November 1900, in his 80th year. [H. B. W.]

Commander the Hon. WILLIAM GRIMSTON was the second son of James Walter, second Earl of Verulam. He was born on January 7th, 1855, and entered the Royal Navy in 1868, from which he retired in 1885 through ill-health, brought on by a gallant action which resulted in the rescue of a seaman who had fallen overboard. He was elected a Fellow of this Society in 1897, and died on May 10th, 1900.

CHARLES JOHN ADRIAN MEŸER was a Fellow of old standing, having been elected into the Society in 1869, though of recent years we have had him rarely among us. He was born on May 23rd, 1832. His inherent love of natural history was fostered by the residence of his family in the country, near Godalming, where his interest was at first especially attracted to bird-life. He there commenced to collect fossils from the Lower Greensand of the district, and in so doing laid the foundations of that intimate knowledge of the Lower Cretaceous Rocks of the South of England which enabled him afterwards to add to our literature a valuable series of papers which will ever remain as a permanent memorial of his labours. As in the case of many another worker who is gratefully remembered in our science, it was only the leisure spared from other duties that he could devote to his geological investigations, for in July 1857 he entered upon a post in the Civil Service, in the Accountant-General's Office, in a division which was subsequently transferred to the Chancery Courts under the title of the Supreme Court Pay Office. During his holidays he repeatedly visited such localities as promised to yield fresh information respecting the rocks in which he was

particularly interested, and was thus able in his papers to look beyond the limits of the object of his immediate investigation and to indicate its general relations. As a fossil-collector he was remarkably successful, and in this respect his services to science are not yet concluded, as his large collection has been presented by the generosity of his sister, Miss C. Meÿer, to the University of Cambridge, where no doubt it will continue to supply valuable material to palæontological workers in the future, as it has already done to Davidson, Lycett, and others in the past.

Mr. Meÿer's first paper was a note 'On the Age of the Blackdown Greensand,' published in the 'Geologist' for 1863; and this was the first of a series which appeared, at the rate of one or more almost every year, in the same publication and its successor, the Geological Magazine, from 1863 to 1869. Of these papers, three dealt with the Brachiopoda of the Lower Greensand, of which some new species were described; one gave a careful account of the Lower Greensand of the Farringdon District; another described, for the first time, the passage of the Red Chalk of Speeton into the underlying clay; and another discussed most ably the correlation of the Lower Cretaceous Rocks of the South-East and West of England. In the last-mentioned paper Mr. Meÿer expressed opinions as to the classification of these rocks differing in some points from those currently held, and his views will require the respectful consideration of future workers in the same field.

In 1869 his well-known paper on the Lower Greensand of Godalming was published as a separate pamphlet by the Geologists' Association, and remains the most detailed account of that neighbourhood which has yet been attempted.

His first communication to this Society was contributed in 1871, and was a description of Lower Tertiary deposits exposed in excavations at Portsmouth. This was followed by papers in 1872 and 1873 on the relations of the Lower Greensand and Weald Clay, having particular reference to the supposed passage-beds or Punfield formation, respecting which he cleared up some difficulties and misconceptions. In 1874 he contributed to our Journal a most valuable account of the Cretaceous Rocks of Beer Head and the Devon Coast, which has already become one of the classic papers on that district. In 1878, in the pages of the Geological Magazine, he discussed the Micrasters of the English Chalk with that catholicity of view that distinguishes all his work, and marked out the lines of research which have since been pursued with such excellent results

to palæontological science. His latest contribution was a joint paper with Mr. A. J. Jukes-Browne on the Chloritic Marl and Warminster Greensand, in the Geological Magazine for 1894. His papers were evidently written with great care, and are characterized by lucidity of expression and arrangement.

Mr. Meÿer was quiet and unassuming in manner, and ever courteous and ready to impart any information that he possessed. He served on the Council of this Society between the years 1871 and 1876. He died on July 16th, 1900. [G. W. L.]

George Highfield Morton, born in Liverpool on July 9th, 1826, was educated at the Paddington Academy, and subsequently at the Liverpool Institute. Though from an early age engaged in business, he devoted all the leisure-time of a long life to geological pursuits, and exerted an influence upon the growth of geological knowledge in his native city which it would be difficult to overestimate.

His earliest specimens, collected during boyhood, he identified for himself at the Museum of the Royal Institute, with the aid of the few men who at that early date possessed the requisite knowledge. In 1845 he was mainly instrumental in forming the Liverpool Natural History Society, which, however, had but a short life. In 1859 he organized and temporarily housed the Liverpool Geological Society, holding the office of Honorary Secretary until the year 1885, and that of President during the sessions 1868–69, 1869–70, 1885–86, and 1886–87.

During the forty years of his membership he read no less than sixty-two papers before the Liverpool Geological Society, nearly all of which contained original observations on the geology of the neighbourhood; while he found time also to contribute several communications to the Literary & Philosophical Society of Liverpool, the earliest dating so far back as 1856. In 1863 he collected his observations in one volume, under the title of 'The Geology of the Country around Liverpool.' In 1891 he brought out a second edition of this work, which was followed by an Appendix in 1897.

This great record of work did not pass unrecognized, and in 1887 he received from the members of the Liverpool Geological Society a handsome testimonial, in appreciation of the great services which he had rendered to local geology. During and after 1864 he had also performed the duties of lecturer at Queen's College, Liverpool, in a manner which led, in 1868, to the presentation of a testimonial from his students 'in appreciation of the great assiduity of their teacher of geology.'

In 1899 he put the finishing touches to a work which had occupied much of his life. Few of the exposures of rock made in and about Liverpool had escaped his notice. By systematically recording upon the 6-inch Ordnance map the faults and boundaries of formations thus revealed, he was in a position, after more than forty years' work, to map the geology of the city with a degree of accuracy unattainable by any other means. In 1899 he allowed copies of those 6-inch sheets to be made for the use of the Geological Survey, the Liverpool Free Library, and the Liverpool Geological Society.

He was elected a Fellow of this Society in 1858, and was presented with the Lyell Medal in 1892, in recognition of his long and meritorious services to Geology in the work done around Liverpool, both on the Triassic rocks and on the Glacial phenomena. He read two papers before this Society, one on Glacial Surface-markings on the Sandstone near Liverpool, published in Quart. Journ. Geol. Soc. vol. xviii (1862) p. 377, and the other on the Carboniferous Limestone of the Country around Llandudno, published in the same Journal, vol. liv (1898) p. 382.

He was a constant attendant at the Meetings of the British Association, and served as Secretary to Section C at Liverpool in 1870, and as Vice-President at Southport in 1883.

Among Mr. Morton's latest and most important researches were those in which he established and traced along the North Wales border a zonal and stratigraphical classification of the Lower Carboniferous Rocks, the last contribution to that series of papers being 'On the Carboniferous Limestone of Anglesey,' which was read before the Liverpool Geological Society eight months after his death. His field-work was conducted on a true method, for he combined the qualities, self-acquired but of no mean order, of a stratigraphist and palæontologist. His papers embody the history of a long and painstaking career in the field; he wrote simply and briefly, for the purpose of recording original observations, and his writings will place future generations of geologists under a lasting obligation.

He died at Liverpool on March 30th, 1900. [A. S.]

A distinguished investigator in that department of Science where Geology borders on Archæology, has passed away by the death of Lieutenant-General Augustus Henry Lane-Fox Pitt-Rivers, F.R.S. To geologists he is probably best known by his discoveries of flint-implements and bones of Pleistocene mammals in the Thames-Valley gravels at Acton and Ealing. At the time of these

discoveries, which were described in our Journal in 1872, he bore the name of Lane-Fox; but, on inheriting the Rivers estates at the death of the sixth Lord Rivers, in 1880, he was compelled to assume the name and arms of Pitt-Rivers, in accordance with the will of his great-uncle, the second Baron.

Born in 1827, the son of Mr. W. A. Lane-Fox, of Hope Hall, General Pitt-Rivers was educated at Sandhurst, and entered the Army in 1845. During the Crimean War he saw much active service. As a young man he became a great collector of weapons and implements, and ultimately formed an ethnological collection of unrivalled interest. This collection he arranged on scientific principles, so as to illustrate the gradual development of form and ornament. After publicly exhibiting the collection for some years in London, under the auspices of the Department of Science & Art, he presented it to the University of Oxford, where a special building was erected for its reception. In 1886 General Pitt-Rivers received from Oxford the degree of D.C.L.

It was during his residence at Kensington, some thirty years ago, that Pitt-Rivers, keeping a careful record of excavations for buildings in his neighbourhood, was led to his interesting discoveries in the Thames gravels. It is noticeable, too, that when visiting Egypt in 1881, he discovered worked objects in chert, embedded in the indurated gravel of the Nile Valley, on the site of ancient Egyptian tombs at Koorneh, near Thebes.

General Pitt-Rivers was an indefatigable explorer of prehistoric remains, having received his introduction to barrow-digging on the Yorkshire Wolds, under Canon Greenwell. When he succeeded to the Rivers estates, he devoted his attention to the exploration of his own property, and his researches are described in four magnificent quarto volumes, under the title of 'Excavations in Cranborne Chase.' These volumes were privately printed, and generously presented to archæological friends and public libraries. General Pitt-Rivers imported into his archæological explorations the scientific methods of the geologist. He observed and recorded the exact position of every object which was unearthed, taking rigid care to avoid the commingling of relics from different layers. No object, however small or seemingly unimportant, was neglected. Before commencing work, he carefully contoured the ground, so that accurate sections could be drawn; and at the close of his investigation, he restored the surface to its original form. At the bottom of most of his excavations he deposited a copper medal, designed by

Sir John Evans, indicating to future explorers that the ground had been disturbed.

General Pitt-Rivers held the office of Government Inspector of Ancient Monuments under the Act of 1882. He was elected a Fellow of this Society in 1867, and of the Royal Society in 1876. After many years of declining health, he died at his seat, at Rushmore, near Salisbury, on May 4th, 1900. [F. W. R.]

Robert Russell, born on May 24th, 1842, was educated as a civil engineer, and joined the staff of the Geological Survey in 1867. For some years he was occupied, under the late Prof. A. H. Green, in the survey of the Yorkshire Coalfield, and afterwards in the Whitehaven Coalfield. He died at St. Bees on May 9th, 1900, aged 58.

Walter Percy Sladen died on June 11th, 1900, at the comparatively early age of 51. He was born near Halifax (Yorkshire) in 1849, and was educated at Marlborough, under Dean Bradley. Apparently without any regular scientific training, his innate love of zoology led him to acquire a wide knowledge of this and collateral sciences. His earliest paper was published in 1877, and for the next 17 years he devoted himself to the study of the Echinoderma, and more especially to the Starfishes. Much of his work was done in conjunction with his friend Martin Duncan. Although his labours were chiefly among the living forms, his intimate acquaintance with these gave him the greater power to deal with the fossils which came under his notice. The outcome of his work was published in the Proceedings of the Royal Society; in the 'Annals & Magazine of Natural History'; in the Journal of the Linnean Society; and in our own Journal; but his great work was doubtless the magnificent volume, of 900 pages and 118 plates, in which he described the Asteroids of the *Challenger* Expedition. His work among the fossil Echinoderma was of no mean order, as shown by the memoir, produced in collaboration with Martin Duncan, on the collections of the Geological Survey of India, and also his continuation of Thomas Wright's Memoir on the Cretaceous Asteroids, published by the Palæontographical Society in the volumes for 1890 and 1893.

Mr. Sladen was for many years Secretary of the British Association Table at the Naples Biological Station; for 10 years he was Secretary of the Linnean Society, and afterwards Vice-President.

He was a Fellow of the Zoological Society, and since 1872 a Fellow of the Geological Society. He was a generous, loving, and trustworthy friend, and will be much missed by those who knew him best. [E. T. N.]

James Thomson, so well known for his researches among the Scottish Carboniferous Corals, was born at Kilmarnock on December 18th, 1823. Of humble parentage he had, when quite a child, to seek employment, and thus contribute to the general support of the family. His education, in consequence, was the outcome of his own strong and earnest nature. The business of his life came to be that of a commercial traveller, in which he continued until upwards of 70 years of age; but his interests were early in life concentrated on natural-history subjects, and on geology in particular. He became a Fellow of our Society in 1868, and was an old member of the Glasgow Geological Society, to whose Transactions he contributed papers on the geology of Campbeltown, Islay, Arran, etc. His chief work, however, was the collection and description of the Corals from the Carboniferous Rocks of Scotland, and his treasures were presented by him to his native town, where they are preserved in the Museum buildings at Elmbank. He was for many years an attendant at the Meetings of the British Association, and there, as elsewhere, his hearty, genial nature won him numerous friends.

He died on May 14th, 1900, in his 77th year. [H. B. W.].

Charles Tylden-Wright, J.P., who died on August 8th, 1900, was an eminent mining-engineer, whose name had been on our roll of Fellows since 1857. The son of the Rev. E. C. Wright, of Pitsford (Northamptonshire), he assumed the name of Tylden-Wright, by Royal licence, on his marriage, in 1860, with Elizabeth, the only child of Sir John Maxwell Tylden. Mr. Tylden-Wright received his education at Marlborough College, and at the Royal School of Mines. For twenty-six years he was Managing Director of the Shireoaks Colliery; at one time he was Chief Agent to the Earl of Dudley, and he also held the position of viewer to the Duchy of Lancaster, to the Duke of St. Albans, and to Mr. Webb, of Newstead Abbey. Mr. Tylden-Wright's only communication to this Society was a description of the sinking through Permian rocks to the Barnsley coal, at Shireoaks, in 1859. He died at his residence at Mapperley Hall, Nottingham, at the age of 68.

[F. W. R.]

George Henry Frederick Ulrich, Professor of Mining and Mineralogy in the University of Otago, was born at Zellerfeld (Prussia) in 1830. He was educated in the High School of his native town, and subsequently graduated at the Royal School of Mines at Clausthal. After four years' service in the Mining Department of the Prussian Government he went to Victoria, where, in 1857, he received an appointment in the Royal Mining Commission. He subsequently joined the Geological Survey of the Colony under the directorship of Dr. Selwyn, and held the office of senior field-geologist at the time of its abolition in 1869. He then became the curator of the mineral section of the Industrial & Technological Museum in Melbourne. In 1875 he paid his first visit to New Zealand, the colony in which he was destined to end his days, and reported on the Otago Goldfields.

Two years later he was appointed Professor of Mining and Mineralogy, in the newly-created Mining School connected with the University of Otago. It was uphill work for some time, but by dint of energy, perseverance, and enthusiasm, he succeeded in getting together the necessary appliances, and finally established a flourishing school whose students are now found in responsible positions, not only in the various States of the Australian Commonwealth, but also in New Zealand, South Africa, and the United States.

He communicated papers to this Society on the Nuggetty Reef of the Mount Tarrangower Goldfield (1870), on the Tin-Ore Discoveries in New South Wales (1873), and on the Nickel-Iron Alloy, Awaruite, from New Zealand (1887 & 1890).

Though hampered of late years by ill-health, his zeal continued unabated till the end, and was, indeed, the cause of his death. On May 26th, 1900, he lost his footing while examining the geology of Flagstaff Point, Port Chalmers, and fell a distance of 100 feet. He never recovered consciousness, and passed away some few hours afterwards.

Wilhelm Waagen, Professor of Palæontology at the University of Vienna, died in that city on March 24th, 1900. He was born at Munich, on June 23rd, 1841, and received there, and at Zurich, a sound scientific education, in which the guidance and influence of his distinguished teacher, Oppel, may be recognized as a leading factor. This was shown by Waagen's early writings; and we must place him, with Neumayr, among the most renowned representatives of Oppel's school.

Following two works on the Jurassic rocks, there appeared three important papers on Jurassic Ammonites, in one of which, 'Die Formenreihe des *Ammonites subradiatus*' (1869), striking out in a then somewhat novel line, the author brought forward the idea of the 'developmental series,' and introduced the term 'mutation.'

After serving for some time in the capacity of scientific tutor to Prince Arnulph and Princess Therese of Bavaria, Dr. Waagen, in 1870, joined the staff of the Geological Survey of India, but ill-health forced him after a few years to retire from that position, and in 1875 he returned to Europe. The principal results of Dr. Waagen's work in connection with the Indian Geological Survey were the voluminous and important monographs on the Palæontology of Cutch and of the Salt Range, published in the 'Palæontologia Indica.' In the former of these (1873–76) the author described the rich Jurassic Cephalopod Fauna of Cutch, and sought to correlate the life-sequence with that recognized in Europe. His work on the Salt-Range Fossils included the description of the *Productus*-Limestone Fauna (1879–87), the excellent 'Geological Results' (1889–91), and an incomplete study of the Ceratite-Formation (1895).

Dr. Waagen subsequently held a position as Lecturer at Vienna University, but in 1879 was appointed Professor of Mineralogy and Geology in the German Technical High School at Prague, and became a contributor to the great work on the Silurian fauna of Bohemia, continued after the death of Barrande. In 1890, on the death of Neumayr, he succeeded to the Chair of Palæontology at the University of Vienna, a position which he occupied until his death.

In addition to the above-mentioned works, Dr. Waagen was the author of numerous papers of less importance, and the unfailing courage and whole-hearted devotion with which, in face of many adverse circumstances, he sought to further the development of palæontological knowledge, never failed to receive fitting recognition. In 1878 the balance of the proceeds of the Lyell Geological Fund was awarded to him, and he became the recipient of the Lyell Medal in 1898. He had been a Fellow of this Society since 1881

Endowed with a delicate constitution, Dr. Waagen was continually forced to struggle against ill-health; but this, and the many difficulties which befell him, he manfully strove to overcome, until seized by a paralytic stroke in 1896, from the effects of which he never succeeded in rallying.

Although Dr. Waagen's researches led him to regard the broad problems of organic development from a point of view with which, perhaps, a majority of his fellow-workers in science are little in agreement, the great value of his labours will be readily conceded. His careful descriptive work, together with many able and suggestive generalizations, form contributions of high importance to invertebrate palæontology. [F. L. K.]

John Young, LL.D., the Curator of the Hunterian Museum in the University of Glasgow,[1] was born in 1823 at Lennoxtown, in the parish of Campsie. When but 10 years old he left school to act as errand-boy at a calico-printer's, in whose employment he remained for 26 years. Meanwhile he had spent his leisure-hours in study, stimulated by the Mechanics' Institute, and had given especial attention to geology. In 1855 he was called upon to assist in arranging, for the meeting of the British Association at Glasgow, a collection of rocks and fossils from the West of Scotland. This work, on which he was engaged for five months, brought him under the favourable notice of the scientific men assembled at Glasgow, and led to his being appointed, in 1859, to the Curatorship of the Hunterian Museum, where he worked under the direction of Prof. John Young, M.D.

His geological researches were carried on chiefly among the Carboniferous Strata of Scotland, and he did excellent service in collecting and mounting the Microzoa, and in studying the Polyzoa and other fossils. He aided largely in the preparation of the useful 'Catalogue of the Western Scottish Fossils,' which was published at Glasgow in 1876, and he contributed papers to the Transactions of the Glasgow Geological Society, the Geological Magazine, and to our own Journal.

He joined the Geological Society of London in 1874; and in 1883 he received an Award from the Murchison Geological Fund, in recognition of his long-continued researches among the Polyzoa and other minute fossil organisms of the Carboniferous Strata of the West of Scotland. He died on March 13th, 1900, aged 77.

[1] We are indebted to an obituary notice by Prof. T. R. Jones in the Geological Magazine, August 1900, p. 382, for some of the above particulars.

THE EVOLUTION OF PETROLOGICAL IDEAS.

Introduction.

The nineteenth century, whose obsequies we have so recently celebrated, was born in what has been aptly termed by Prof. Zittel, our latest historian, the heroic age of geology. Geological Societies and Geological Surveys did not then exist. Cooperative work was unknown; but a few individuals, of great power and originality, were laying the foundations of our science on a firm basis of accurate observation. Pallas had recently carried out his remarkable researches in Eastern Russia, and had noted the extraordinary abundance of the remains of the mammoth, rhinoceros, and bison in the superficial deposits of the Siberian plains. De Saussure had climbed Mont Blanc, and published his unrivalled descriptions of Alpine scenery and Alpine structure. Werner was still acting as an exponent of the science which he had done so much to foster, and had fired his two most illustrious pupils, L. von Buch and Humboldt, with that enthusiasm for natural knowledge which was destined to produce such glorious results. Hutton had just passed away, after giving to the world his Theory of the Earth, the main features of which form the basis of modern geology. Smith and Cuvier, both born in the same year (1769), were in the prime of life, and actively engaged in those researches which placed stratigraphical geology on a secure foundation. These are some of the heroes of our science.

The early history of geology is mainly a record of fantastic speculations; but in the heroic age it was beginning to be recognized that no solid advance could be made, except on a basis of carefully observed fact. A reaction against the wild speculations of the seventeenth and the greater portion of the eighteenth centuries had set in, and this led, among other things, to the foundation of our Society—the parent of all such societies—in 1807.

That it was necessary to put a curb on the unbridled licence of geological speculation, and to emphasize the importance of diligence and accuracy in the observation of facts, will be admitted by all students of the history of our science; but it is well to remember that there is a scientific, as well as an unscientific, use of the imagination. The chief glory of science is, not that it produces an amelioration of the conditions under which we live, but that it

continually enlarges our view, introduces new ideas, new ways of looking at things, and thus contributes in no small degree to the intellectual development of the human race.

It is now generally recognized that the state of advancement of a science must be measured, not by the number of facts collected but by the number of facts coordinated. The old Baconian idea that it was only necessary to collect facts and pigeon-hole them according to rule, in order to make the most brilliant discoveries, has been somewhat discredited by the history of scientific progress. Speaking on this subject, De Morgan says :—

'Modern discoveries have not been made by large collections of facts, with subsequent discussion, separation, and resulting deduction of a truth thus rendered perceptible. A few facts have suggested an hypothesis which means a supposition proper to explain them, the necessary results of this supposition are worked out, and then, and not till then, other facts are examined, to see if these ulterior results are found in Nature. .... What are large collections of facts for? To make theories from, says Bacon; to try ready-made theories by, says the history of discovery; it's all the same, says the idolater; nonsense, say we.'

Hutton appears to have been of De Morgan's way of thinking. He pondered over the facts that he had observed in England, France, and Scotland, and formulated his theory of the earth. He then went again into the field to test the consequences of his theory, and verified them. He never seems to have thought it worth while to describe isolated facts, or the structure of particular districts, except in so far as they illustrated his theory: although no one was better qualified to do this, as all readers of his description of the unconformity at Siccar Point, of the granite-veins in Glen Tilt, or of the geological features of Arran, will readily admit. His joy at the discovery of the granite-veins in Glen Tilt can be easily understood. His theory required that they should exist, and they were found, not by chance, but because they were looked for. And we may be sure that the joy did not arise from gratified vanity, for, as Playfair says, he was one of those who took more delight in the contemplation of truth than in the praise of having discovered it.

In thus calling attention to the importance of ideas in scientific research, I trust it will not be thought that I am advocating a return to the condition of things which prevailed in the early days of geological history. Armchair philosophizing, apart from actual work in the field, the laboratory, and the museum, is by no means to be commended. But the worship of fact, as fact, may easily be overdone. The number of discoverable facts is practically infinite,

and it is therefore possible to get into such a condition as not to be able to see the wood for the trees, to lose the due sense of proportion, and to become mere machines for tabulating interminable trivialities.

On the other hand, it should be remembered that every worker endowed with imagination must formulate, in his own mind, many theories that will not stand the test of verification, and that it is quite unnecessary for him to trouble other workers with such theories. He can test them for himself, and relegate them to oblivion if necessary, without burdening our overcrowded bookshelves with crude speculations and unverified hypotheses.

It is only when a theory has proved its usefulness as a coordinator of fact that it becomes worthy of the dignity of publication. It may be true, or false, most likely the latter; but if it coordinates more facts than any other, it is at any rate useful, and may be conveniently retained until replaced by a better. Controversy as to the truth or falsity of a theory often seems to me beside the mark, for if a given theory coordinates more facts than any other, it is at least worthy of respect, and may be tentatively held as a working hypothesis, along with the conviction that it is not true, or only partially true. Indeed, the controversial spirit is, in my judgment, inimical to the best interests of science. It makes a man more eager to refute than to understand the views of his opponents; it tends to check the flow of sympathy, and thus often prevents that friendly cooperation which is so desirable in the interest of scientific progress. When controversy becomes acute, I always feel inclined to exclaim 'a plague on both your houses!'

Every branch of our many-sided science has benefited by the zeal for collecting facts which manifested itself during the early years of the nineteenth century. Methods of observation have been perfected, national surveys and private individuals have examined, and are examining, the geological structure of every civilized State, and explorers have penetrated to almost every quarter of the globe. Our libraries and museums are being rapidly filled with records of all this scientific activity. Side by side with the registration and cataloguing of facts there has taken place an evolution of scientific ideas, and it is on this aspect of the subject, so far as my own special branch is concerned, that I propose to offer a few remarks.

Rocks may be studied from two more or less distinct points of view, the descriptive and the ætiological. But it is well to note

that the distinctness of these two points of view is but the expression of our ignorance as to the genetic relationships of the different types. Facts as to composition, structure, and the like, accumulate faster than they can be interpreted; and our classifications are, therefore, necessarily more or less artificial. But there is that within us which compels us to bring our classifications into accord with our views as to genesis. Phylogeny must in the end control classification, both in the organic and inorganic worlds. As soon as we realize that any scheme of classification places together objects which have no genetic relationship, or groups them irrespective of such relationship, we become dissatisfied with it. The old classifications need not be thrown over the moment that their imperfections are glimpsed; but in the end they have to be discarded, and the new ideas find expression in a new classification. Thus

Thro' the ages one increasing purpose runs,
And the thoughts of men are widened with the process of the suns.

How far Hutton was in advance of his time on matters relating to petrogenesis is illustrated by the fact that more than half a century elapsed before his ideas found expression in systematic treatises. Yet the separation of rocks into igneous, sedimentary, and metamorphic, and the further subdivision of the igneous rocks into plutonic and volcanic, follow naturally and logically from his fundamental conceptions.

The reason for the tardy recognition of what is now generally admitted to be the true basis of classification is not far to seek. Hutton was no systematist. Werner, on the other hand, was not only a keen observer, but he possessed in quite an exceptional degree the power of describing what he observed in precise and definite terms, and of grouping his facts according to their supposed relationship. He was, in short, a born systematist, and this, combined with his eloquence and enthusiasm, gave him a commanding influence. In looking back at these two striking figures of the heroic age, Werner and Hutton, it is almost impossible to avoid a feeling of regret that the one did not possess what the other lacked. But such regrets are useless. Let us honour them both.

The authors of systematic treatises on rocks published during the first half of the century were all under the spell of Werner, and they were still further hampered by their ignorance of the composition of those rocks which are of so fine a grain that their constituents cannot be determined with the naked eye, or with the aid of a simple magnifying-lens. The treatises of Haüy, Brongniart,

and Leonhardt clearly recognized the great natural group of fragmental rocks; but the true limits of the other equally natural groups were, so far as general treatises are concerned, brought into prominence for the first time in the work by Von Cotta, the English translation of which appeared in 1866.

Progress during the First Half of the Century.

Igneous rocks played but a small part in the Wernerian system. They were regarded as stratified rocks melted by heat, due to the burning of coal beneath volcanic districts. We now recognize that they are of great importance, and probably represent the original source of all the other rocks. The clearing up of our ideas as to their nature and mode of origin centres round two controversies: one as to the origin of basalt, the other as to the origin of granite.

It is difficult for us to realize the condition of things which prevailed during the early years of the century, when the martial spirit of the age seems to have affected the scientific world, and a furious controversy raged between the Neptunists and the Vulcanists as to the origin of basalt. We look with a feeling of astonishment at the controversialists, condemn their methods, and admire the calm figure of the old man Desmarest as he sits there refusing to be dragged into the controversy, and quietly replies to his challengers 'Go and see.' Now and again, in looking through some neglected cabinets of our museums we come across dust-covered specimens labelled 'Ammonites in Basalt from Portrush,' and are thus forcibly reminded of those stirring times.

The controversy as to the origin of granite lasted longer, and during its later stages, at any rate, was conducted with dignity and a due regard to the amenities of scientific discussion. It resulted, moreover, in a very decided enlargement of our conceptions as to subterranean phenomena. The Wernerian view that granite was a precipitate from a primordial ocean was compelled to give way as soon as the tectonic relations of granitic masses, so well described by Hutton, Playfair, and Sir James Hall, were clearly realized. The phenomena of granite-veins, the occurrence of inclusions of the surrounding rocks, and the sharpness of the junctions between granite and the strata with which it is in contact, prove beyond all doubt that the material of which many granite-masses are composed must have been intruded from below in a plastic state. Towards the

middle of the century these facts were generally recognized for all those masses which occur outside areas of crystalline schist. But their recognition, although conclusive as against the view that granite was everywhere a primordial sediment, by no means involved the necessity of accepting the Huttonian theory that it resulted from the consolidation of a mass of matter in a state of pure igneous fusion.

The earlier phases of the discussion as to the origin of granite centred mainly round the tectonic relations of the rock-masses; but the later phases had reference rather to the composition and structure of the rock itself. The papers on this subject, and especially the discussion between Scheerer and Durocher, are well worthy of the attention of modern petrologists.

Scheerer maintained that the purely igneous origin of granite was disproved by three lines of argument. Thus he contended that the very presence of quartz was opposed to the theory, for this mineral could not be formed by igneous fusion, and was absent from lavas containing an excess of silica, such as obsidian, even when these lavas must have cooled more slowly than some granite-veins.

Again, the order of consolidation of the minerals, as determined by mutual interference, was not the order of their fusibilities. Fournet had endeavoured to remove this objection by supposing that quartz, like water and sulphur, could be cooled below its proper melting-point. But this theory of the surfusion of quartz was untenable, because the amount of overcooling was too great and the complete rest which was necessary could not be postulated. Scheerer admitted that the objections to Fournet's theory were rendered less forcible by a consideration of the fact, pointed out by Durocher, that the magma of granite did not contain the material of the separate minerals in a fused state, but consisted of a homogeneous liquid—a solution as we should say—so that the overcooling did not affect quartz as such. This, however, in his opinion, did not justify the theory, for, to use a free translation of his own words,

'it is evident that the point of solidification of the silicate forming the magma out of which the different compounds are separated, ought to approach the fusion-point of silica as the quantity of bases in the liquid portion decreases.'

According to Durocher's view, the ultimate base of granite should consist, not of quartz, but of a substance like petrosilex.

A third line of argument, founded on the occurrence in some granites of the peculiar pyrognomic minerals, such as gadolinite, was also brought forward by Scheerer. If a chip of isotropic gado-

linite be heated to redness, a sudden and remarkable change takes place. It glows brightly for a few moments, and after cooling is found to have become denser and strongly birefringent. Thus gadolinite occurs in two phases: a lighter isotropic phase, and a denser birefringent phase. The change from the former to the latter takes place at a red heat, and the reaction is accompanied by a considerable loss of energy, but little or no loss of material. The occurrence of this mineral in some granites proves, therefore, according to Scheerer, that they must have consolidated below a red heat.

These three lines of argument, based on the presence of quartz, on the mutual relations of the constituents, and on the presence in some granites of pyrognomic minerals, concur, he considers, in disproving the theory of pure igneous fusion.

Scheerer then propounds his own theory of aqueo-igneous fusion, basing it on the fact that some of the granitic minerals, such as mica, contain water. The presence of even small quantities of water would, he maintains, lower the consolidation-point considerably, and during consolidation the water would concentrate in the mother-liquor, and ultimately in the silica. Final consolidation would take place on the escape of the water. Thus the paradoxical order of crystallization would be explained, and the granite might consolidate at a temperature which would admit of the formation of the pyrognomic minerals.

The theory of Scheerer was opposed by Durocher, and the controversy between these two distinguished men extended over a period of three or four years. Durocher considered that a close examination of the structure of granite does not bear out the view that there is a well-defined order of consolidation. The minerals mutually interfere one with the other, sometimes one, and sometimes another, having the advantage. The magma appears to have cooled down to a comparatively low temperature, and then to have separated into definite compounds which did not solidify instantaneously. The relative perfection of form would, on this view, be largely determined by the relative power of crystallization of the different constituents. In this respect quartz is at a disadvantage. It possesses, moreover, as shown by M. Gaudin, a great range of viscosity, and when fused can be drawn into threads like glass and sealing-wax. He agrees with Scheerer in rejecting Fournet's theory of surfusion, and considers that the paradoxical order of consolidation can be explained by taking into consideration the wide range

of viscosity of quartz and its slight tendency to crystallize. A similar view has recently been advocated by Prof. Joly. Durocher replies to Scheerer's argument derived from the absence of quartz in obsidians, by pointing to its presence in trachytes, and attempts, somewhat unsuccessfully, to explain away the presence of the pyrognomic minerals. In his criticisms of Scheerer's views as to the amount of water present in granite he is often effective, for he shows that sufficient allowance had not been made for the effects of alteration.

Scheerer's view became the popular one, and is now generally held. It was greatly strengthened by Dr. Sorby's discovery of the widespread distribution of liquid cavities containing water in the quartz of granites, and by the well-known synthetic experiments of Daubrée and others. The failure of all attempts to produce granite is also still felt to be a strong argument against the theory of dry fusion.

Scheerer concludes the discussion with some observations which I cannot refrain from quoting. He says:—

'To avoid misunderstanding, I desire to make some remarks on the value which I attach not only to my theory of the origin of granite, but also to geological theories in general. I am far from believing that the igneous theory, which M. Durocher defends with so much vigour, is finally disposed of, or that my theory is completely satisfactory. Such definite conclusions cannot be reached in the present state of our science. More than one point of view is possible on almost every subject of this kind, and thus it must ever be, for mathematical certainty is unattainable.

'A short time ago it seemed as if the Neptunean theories had completely abandoned the field in favour of those volcanic theories which appeared so absurd to our ancestors. Now the Neptunean theories are beginning to show signs of life. I have endeavoured to conciliate the two sister-enemies by suggesting that water may play an important part in the formation of fused rocks. . . . I do not pretend, however, that my theory is unassailable, or that it has been absolutely demonstrated. . . . In my opinion a geological theory should not be considered as absolute; but it becomes probable when a considerable number of facts group themselves around it, and its degree of probability can be measured by its power of assimilating the new facts brought to light by the progress of science.'

These are wise words, and may well be remembered when differences of opinion tend to become sharply accentuated. The path of science is littered with discarded theories, and this fact should serve to remind us that 'we are none of us infallible, not even the youngest.'

In the discussion between Scheerer and Durocher attention was

directed to the mutual relations of the constituents of granite and to the inferences which could be drawn from a study of those relations as to the order of consolidation of the minerals.

The Consolidation of Igneous Magmas.

At the time when the discussion took place this kind of reasoning could be applied only to coarse-grained rocks, but with the advent of the microscope it became possible to extend it to the important group which had been designated, in the earlier classifications, as 'apparently homogeneous rocks.' In the early part of the century Cordier had proved, by the microscopic examination of the powder of basalt, that this rock was heterogeneous, but it was not till the examination of thin sections had been introduced that the mutual relations of the constituents of the finer-grained rocks could be studied. In those rocks which have resulted from the consolidation of homogeneous silicate-magmas, and in which the consolidation has been unaccompanied by the phenomena of resorption—that is, in which there has always been equilibrium between the constituents during the process of consolidation—the order of separation can be inferred from the microscopic structure.

It has thus been established that the process of consolidation cannot be divided into a number of sharply-defined periods, each characterized by the separation of some one mineral only; but that the times during which the different minerals are separating out overlap to some extent. The amount of overlapping varies in different cases, and, in one and the same magma, is most marked in plutonic masses; whence we conclude that it is largely determined by physical conditions, and especially pressure.

The order of consolidation, as determined by an examination of the mutual relations of minerals, is, therefore, the order in which they commence to form, and this order may or may not agree with that in which they cease to form. The laws which express the order of formation of minerals, and the chemical and physical conditions which control that order, have not as yet been definitely established.

One of the most important papers on theoretical petrology is undoubtedly that by Prof. Rosenbusch on the significance of the granular and porphyritic structures in massive rocks. The importance of this paper must not be judged simply by the amount of truth in the principles enunciated, but rather by the stimulus which it gave to theoretical considerations and to researches

directed towards a particular end. The constituents of massive rocks are divided by Prof. Rosenbusch into four groups :—

1. The ores and accessory constituents (magnetite, hæmatite, ilmenite, apatite, zircon, spinel, and titanite).
2. The ferromagnesian constituents (biotite, hornblende, pyroxene, and olivine).
3. The felspathic constituents (felspar, nepheline, leucite, melilite, sodalite, and haüyne).
4. Free silica.

Prof. Rosenbusch pointed out that members of the first group precede those of the other groups; that in granites and syenites the members of the second group precede those of the third; but that in the diabases and gabbros the order is inverted, and that in both groups silica is the last. The general conclusion is reached that

'the order of consolidation of the silicates and, consequently, their crystallographic development (idiomorphism), corresponds to a law of decreasing basicity; the ores and accessory minerals are the earliest, and quartz is the latest, product of the rock-forming process.'

This empirical law expresses, in a broad and general way, the main facts observed with regard to the sequence of minerals in thelarge and important group of intermediate rocks, but it breaks down when applied to the most acid and the most basic rocks; quartz is often formed before felspar in the former, and iron-ores are not infrequently formed after felspar in the latter.

The views that we hold regarding the laws which express the order of consolidation in igneous magmas will necessarily be coloured by our conceptions as to the nature of these magmas. A great advance in the evolution of ideas on this subject is marked by a short letter, written by Bunsen to Streng, and published in the Journal of the German Geological Society for 1861. In this letter Bunsen points out that the arguments against the igneous origin of granite, so far as they rest upon the so-called anomalous order of consolidation of the minerals, are based on a misconception of the nature of the process of consolidation. He says :—

'The temperature at which a substance consolidates from a state of fusion is never that at which it separates from a solution in another substance. The temperature at which a definite substance crystallizes from its own liquid depends only on the substance and on the pressure to which it is subjected; whereas the temperature at which the same substance separates from its solution in another substance depends principally on the relative proportions of the two substances. No chemist will fall into the error

f 2

of assuming that a solution ceases to be a solution at 200°, 300°, 400°, 500°, or even when heated to a temperature at which it becomes self-luminous; or will suppose that a crystalline aggregate of ice and calcium-chloride which has become fluid is a solution, but that a mixture of quartz and felspar which has been fused is not.'

He then proceeds to point out that the laws which govern the solidification of aqueous solutions must hold good also for igneous solutions; that by the addition of a certain amount of calcium-chloride to water the temperature may be lowered to −10° C. without the separation of any solid substance; that by the addition of further amounts the temperature of consolidation of water may be lowered as much as 59°, and that of calcium-chloride 100°. Other salts, such as the sulphates and nitrates of potassium, may be made to separate from aqueous solutions at temperatures from 600° to 800° below their freezing-points; moreover, the order of consolidation is determined by the relative amounts of the two substances present; thus water may be made to consolidate before or after a dissolved salt, by varying the concentration of the solution.

I have given a somewhat full abstract of this important letter, because I believe that the expansion of the idea which it contains will be the characteristic feature of the next great advance in petrological science, an advance which will come about, not so much by adding to our already large store of facts, as by dint of experiment controlled by the modern theory of solutions, and carried out for the express purpose of testing the consequences of that theory and discovering the modifications which may be necessary to adapt it to igneous magmas.

Almost all recent writers on theoretical questions relating to the igneous rocks have accepted the solution-theory, and the condition of formation of minerals has been discussed from this point of view. Crystals tend to form in a homogeneous liquid mass when the liquid becomes supersaturated with any definite compound. As soon as crystals are developed the liquid in their immediate neighbourhood ceases to be supersaturated, and there is thus established an osmotic force producing molecular flow from the supersaturated portions towards the growing crystals.

From a consideration of the work of Pelouze on glasses, combined with his own work on igneous rocks, Lagorio arrived at the conclusion that the ordinary rock-forming compounds tend to separate out in the following order: oxides, pure iron-silicates, magnesian and ferromagnesian silicates (olivine and rhombic

pyroxenes), calc-magnesian silicates (monoclinic pyroxenes and hornblende), silicates of magnesium and potassium or of iron and potassium (biotite), calcium-silicate (anorthite), silicates of sodium and calcium (plagioclase), sodium-silicates (nepheline and albite), and lastly potassium-silicates (orthoclase) in conjunction with quartz.

In his important work on slags, Prof. Vogt has clearly established the influence of the relative proportions of the bases to each other and to silica in determining the nature of the compounds which separate out. Thus in slags in which the ratio of bases to silica corresponds approximately to that found in bisilicates, the ratio of CaO : MgO determines the formation of such minerals as enstatite, augite, and wollastonite. When the ratio of MgO + FeO : CaO is greater than 2·44 : 1, enstatite forms; when the same ratio is less than 1·4 : 1, augite separates out, and continues to do so, until this ratio becomes less than ·35 : 1; with a still further diminution in the ratio of magnesia to lime, wollastonite is formed.

In slags having approximately the composition of monosilicates the ratio of MgO + MnO + FeO : CaO determines the formation of olivine or melilite. When the above ratio is greater than 1 : 1·1 (in slags with about 20 per cent. of alumina), olivine is formed; but when it is less than 1 : 1·25, melilite is produced.

The general conclusion arrived at as a result of the work of Vogt, Lagorio, and others, is that mass-action and the affinities of the bases to each other and to silica are the two factors of primary importance in determining the molecular grouping, so long as the pressure remains constant. The action of alumina may be especially referred to, as illustrating the influence of the mutual affinities of the so-called bases. In the sorting of partners in accordance with the law of mass-action, this substance, when present in sufficient quantity, practically takes the whole of the alkalies and as much of the lime as is necessary to make felspathoid molecules. So marked is this action that M. Michel Lévy and M. Osann, in calculating the results of analyses, combine the whole of the alumina with the alkalies, when the latter are present in sufficient quantity, and associate any excess of alumina with lime in the form of felspathoid molecules. It is only in those rocks that contain an abnormal percentage of alkalies that minerals like ægirine and riebeckite occur.

This controlling influence of alumina, which has also been emphasized by Prof. Iddings, has the most far-reaching effects in determining petrographical species. It is as if there were a kind of

repulsion between the ferromagnesian and alumino-alkaline constituents. Dark rocks rich in the former, and light rocks rich in the latter, represent the extreme forms of many intermediate types; and Prof. Brögger has recently proposed that this should receive expression by the application of the terms melanocratic and leucocratic to these two strongly-contrasted varieties.

The results already obtained leave no doubt that a properly-directed series of experiments will throw great light on the laws which control the formation of minerals during the consolidation of igneous rocks. The classic researches of Prof. Fouqué and M. Michel Lévy on the synthesis of such rocks as basalt, andesite, and nephelinite by pure igneous fusion show that we can control the necessary physical conditions, and that the whole subject, so far at least as these rocks are concerned, lies within the range of experiment.

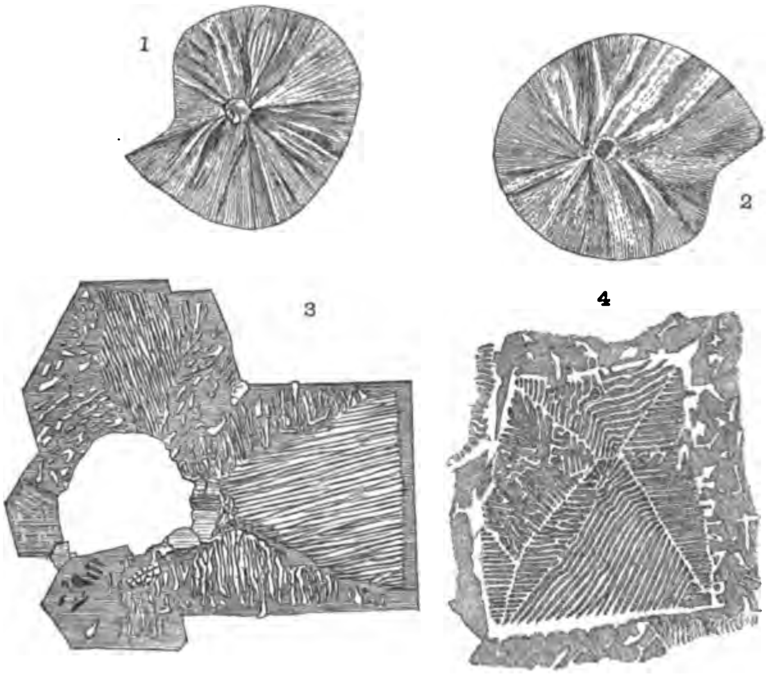
The work of Morozewicz, to which I have directed attention in another place, may be mentioned as proving that a rich harvest of results may be confidently anticipated from experimental work in this direction.

To return to the question of the order of consolidation of minerals in igneous rocks. If the solution-theory be true, no order based solely on a consideration of the properties of the minerals can hold good in all cases. In the case of aqueous solutions of two substances the order of separation, as pointed out by Bunsen, depends on the relative proportions of these two substances. This subject, so far as alloys, fused salts, and aqueous solutions are concerned, was investigated with great skill by Prof. Guthrie, the importance of whose work on alloys has been brought into prominence of late by the researches of Roberts-Austen, Le Chatelier, Osmund, J. E. Stead, Heycock & Neville, Alder Wright, and others.

It is too early yet to discuss the full bearing of this recent work on petrographical questions, but it is impossible to examine the beautiful photographs which illustrate the structure of alloys, such, for example, as those accompanying the Fifth Report of the Alloys Research Committee,[1] or those illustrating Stead's paper on iron and phosphorus,[2] or Heycock & Neville's paper on gold-aluminium alloys,[3] without being struck by the resemblance of many of these structures to those met with in rocks.

[1] Fifth Report by Sir William Roberts-Austen, Proc. Inst. Mech. Eng. 1899, p. 35.
[2] Journ. Iron & Steel Inst. vol. lviii (1900) p. 60.
[3] Phil. Trans. Roy. Soc. vol. cxciv (1900) A, pp. 201-32.

Some years ago I directed attention to the possible application of Guthrie's work on cryohydrates and eutectics to petrographical questions, and the experience since gained has tended rather to confirm me in the views which I then expressed. Fused salts which do not act chemically upon each other show, when mixed in eutectic proportions, a marked tendency to form spherulitic, and what may be called micropegmatitic, intergrowths. It has since been proved that the same is true of alloys. Thanks to the kindness of Mr. J. E. Stead, I am able to give two figures, drawn from photographs, which illustrate this fact, and side by side with these are placed figures of micropegmatitic and spherulitic structures copied from Prof. Iddings's memoir on the rocks of Obsidian Cliff.



Figs. 1 & 3 = Spherulitic and micropegmatitic structures in obsidian. (After Iddings, VIIth Ann. Rep. U. S. Geol. Surv. 1885–86, pl. xv.)

Figs. 2 & 4 = Similar structures in eutectic alloys: from microphotographs by Stead. 2 = A simple spherulite in the eutectic of lead and antimony[1]; 4 = Micropegmatitic structure in magnolia-metal (lead, 80 per cent.; antimony, 15 per cent.; and tin, 5 per cent.).

[1] The outlines of this spherulite are somewhat too sharply drawn.

In the case of the alloys the spherulitic structures are characteristic of rapid cooling, and the micropegmatitic structures of slow cooling. The mode of occurrence of the same structures in rocks is strictly in accordance with this view. A comparison of the structures in the two cases makes it almost impossible to believe that the resemblances are merely accidental, and if not, they point to the conclusion that micropegmatite is an eutectic compound.

From this point of view it becomes of interest to determine the melting-point of fused micropegmatite. This was kindly done for me by Prof. Joly, by observations with the meldometer. He found that fused micropegmatite melted somewhat more readily than orthoclase, but less readily than fused orthoclase. These observations do not support the eutectic hypothesis, but they can scarcely be said to negative it, as the conditions of the experiment are certainly very different from those under which the rocks are produced.

Quartz and orthoclase have not as yet been formed by pure igneous fusion. The melting-point, at atmospheric pressure, of a mixture of quartz and orthoclase is above that of basalt, and yet we know from the occurrence of angular fragments of basalt in granophyre, that the consolidating-point of the mixture under certain conditions of pressure is below that of the fusing-point of basalt under the same conditions. If, as Prof. Lœwinson-Lessing's calculations suggest, the formation of felspathic minerals is accompanied by an increase in volume, and the formation of ferromagnesian minerals by a decrease in volume, pressure will lower the fusing-point of the former and raise that of the latter, so that, under plutonic conditions, the relative order of consolidation of acid and basic magmas may be the reverse of that under volcanic conditions. Magmas usually contain water, and sometimes other volatile constituents (such as chlorine, boron, fluorine, etc.), whose importance in determining the fluidity and the molecular grouping of the constituents has been generally recognized since the publication of the classic paper 'Sur les Emanations Volcaniques & Métallifères' by Elie de Beaumont. When separated from the magma, these constituents exercise most important metamorphosing and mineralizing effects, as is well seen in the phenomena accompanying the formation of tinstone and apatite-veins, in the development of zeolites, and in the production of large masses of kaolin. But, so

long as they remain in the magma, they must be regarded as belonging to it, and playing their part along with the other constituents in producing the final result.

The application of the theory of solutions to igneous rocks is complicated in many ways. We are ignorant of the manner in which the constituents revealed by analysis are distributed in the molten magmas, and of the changes which take place in the molecular groupings as the temperature approaches the point of saturation. M. Le Chatelier has recently suggested that granite furnishes an illustration of the phase-rule, and may be regarded as a stable system of three phases (quartz, felspar, and mica), made up of the three components—silica, alumina, and potash. Few petrographers will admit that the case can be put as simply as this. No doubt the consolidation of igneous magmas is governed by the phase-rule, but in the majority of cases the number of components, on any view as to their nature, is too great to make the rule of much practical value. Another cause of complication arises from the fact that the physical conditions have often changed during the process of consolidation, thus giving rise to the phenomena of resorption; and yet another from the absence of assurance that the minerals seen in a rock have in all cases been developed from a magma having the composition represented by the bulk analysis.

I cannot leave this portion of the subject without calling attention to the recent work of Prof. Joly on the melting-points of the rock-forming minerals, and his proof of the enormous range of viscosity possessed by quartz and other minerals.

Whatever view we take as to the nature of silicate-magmas, there can be no doubt that in general the process of consolidation is a process of differentiation. Definite compounds separate out, either successively or simultaneously, from a homogeneous magma, and at the time of their formation are in equilibrium with the surrounding liquid; but owing to changes in temperature and pressure the equilibrium established at one period may be destroyed at another, and the igneous rock as we see it may not contain a record of all the operations which have taken place during the process of consolidation. So far as individual rocks are concerned, we look to experiment, rather than to observation, to give precision and definiteness to our ideas regarding the nature of the changes which accompany solidification.

THE ORIGIN OF SPECIES.

The geologist, however, has to deal not only with igneous rocks as individuals but as groups, to consider their mutual relations, their geographical distribution and mode of origin. But to give anything like a full account of the growth of ideas on this subject would expand this address to an inordinate length, and would, moreover, be a work of supererogation, for the whole question has been admirably reviewed by Prof. Iddings and Prof. Lœwinson-Lessing.

The germs of all the theories which are now struggling for existence can be discovered in the writings of our predecessors. Scrope (1825) held the view that lavas were formed from previously crystallized rocks, such as granite, and maintained that in the process of eruption, or intumescence as he termed it, a kind of differentiation might take place, giving rise to trachyte and basalt. Darwin (1844), in his important work on Volcanic Islands, also discussed the origin of petrographical species. He directed attention to two causes of differentiation which may ultimately prove to be of great importance—(1) the movement of crystals in a magma under the influence of gravity; and (2) the squeezing or leaching-out of the more fusible constituents from a partially consolidated or partially fused mass. The first of these he illustrated by the well-known Pattinson process for desilverizing lead, and the second might be illustrated by another metallurgical process often known as liquation (but quite distinct from the process referred to by Durocher under the same name), by means of which silver is separated from blister-copper. The copper is fused with a certain proportion of lead, and the bars are maintained at a temperature above the fusing-point of the silver-lead alloy and below that of copper. The silver-lead alloy is thus leached out of the copper, which remains as a solid porous mass. Such a separation might be effected in the case of a plutonic mass, if a partially solidified magma were subjected to pressure under conditions which admitted of the escape of the still liquid portions into the surrounding rocks. As a matter of fact it has been so applied by Mr. Barrow, who thus explains the relation between pegmatites and certain oligoclase-biotite-gneisses in the Southern Highlands of Scotland. The eurite-veins in granite are generally supposed to owe their origin to a somewhat similar action, but in this case the separation is due to the leaching-out of the still liquid eutectic into cracks in the nearly consolidated mass, and not to orogenetic movements. It is comparable, therefore, to the liquation-process above mentioned.

Bunsen explained the varieties of igneous rock revealed by his analyses by assuming the independent existence of two magmas—the 'normal pyroxenic' and 'normal trachytic'—and supposing a process of intermixture to account for the intermediate varieties. Von Waltershausen thought that igneous magmas were arranged in a series of concentric shells, according to specific gravity. Durocher, in his celebrated essay on Comparative Petrology, maintained

'that all igneous rocks, modern and ancient, were derived from two magmas which co-exist below the solid crust of the globe, and occupy there each a definite position.'

His two magmas—basic and acid—do not differ materially from those of Bunsen, and his idea of their arrangement in the earth's crust is practically the same as that of Von Waltershausen. He compared the two magmas to baths of fused metals, which separate into distinct alloys on cooling. He does not give actual illustrations, but we may consider one, in order to give precision to the idea. A mixture of 43·64 per cent. of bismuth and 56·36 per cent. of zinc separates at a temperature between 700° and 800° C. into two alloys, which arrange themselves according to specific gravity. On cooling, the heavier is found to contain 84·82 per cent. of bismuth and 15·18 per cent. of zinc; the lighter 2·47 per cent. of bismuth and 97·53 per cent. of zinc. If silver be added to the mixture, there is also a separation into two alloys, so long as the amount of silver is less than about 40 per cent.; when it exceeds this amount, there is no longer any separation.

Durocher speaks of eruptions which derive their supply from the primary magmas as belonging to the first order, and those which draw their material from more or less isolated magma-basins as belonging to the second order. The latter furnish rocks which depart from the normal type, and this he explains, in part at least, by assuming a process of separation analogous to that by which the primary magmas were produced. Thus he says:—

'It is therefore probable that phonolitic and trachytic porphyry are only the two opposite products of a liquation which took place in the midst of the fluid mass; they are, as it were, the two inverse alloys into which we so often see a metallic bath divide itself.'

The type of magmatic differentiation conceived by Durocher may be illustrated by a very simple experiment. Place some phenol and water in a Florence flask: two immiscible conjugate solutions will be formed—a solution of water in phenol at the bottom, and a solution of phenol in water at the top. Now heat the mixture to

69° C., and a perfectly homogeneous solution will be produced. On cooling, this will again break up into two. Clouds are first formed in the cooler portions of the liquid, and after the coalescence of the minute drops, gravity is able to effect a perfect separation of the two solutions.

Do silicate-solutions behave in the same way? Bäckström has recently argued that they do; but until the fact has been definitely established by experiment, there will always remain a certain element of doubt. The sharp separation of basalt and granophyre, which is so striking a feature of the Brito-Icelandic province, suggests that the two magmas represented by these rocks may separate in the manner just described. But the great viscosity of fused granophyre at atmospheric pressure and easily accessible temperatures would probably prevent the attainment of any decisive result.

Clarence King maintained that local lakes of fusion were formed by relief of pressure, and that differentiation took place partly by liquation in Durocher's sense, and partly by the rise or fall of crystals.

The physico-chemical speculations, which played so important a part in the science of rocks during the middle of the century, were neglected for a time, in consequence of the opening up of a new field of observation by the introduction of the microscope; but of late years we have returned to these speculations with renewed vigour, and with a wealth of facts at our disposal which the earlier theorists would have envied.

The mineralogical composition and microscopic structure of all kinds of igneous rocks have been determined, reliable chemical analyses have been made, and the problem of the origin of petrographical species has resolved itself into the question of the evolution of the magmas. Especially noteworthy is the stimulus given to the chemical side of petrology by the magnificent work of the United States Geological Survey. We have now some four or five new and original classifications of igneous rocks largely based on the analyses of Clarke, Hillebrand, and their assistants, and the cry is—'still they come!' But the authors of these analyses have hitherto refrained—perhaps wisely—from attempting any general classification of rocks from a chemical point of view. The number of constituents is so large that there is no reason, so far as I can see, why every petrographer should not have his own classification and his own method of graphical representation.

The idea that petrographical species have originated by differentiation from homogeneous magmas, and possibly in the first instance from some one primordial magma, has been greatly developed during the last decade of the century, especially by American and Norwegian petrographers. Thus Prof. Iddings, in the introduction to his important memoir on the Origin of Igneous Rocks, says:—

'The object of the present paper is to give the writer's reasons for concluding that all of the volcanic and other igneous rocks of any region are so intimately connected together by mineralogical and chemical relations that they must have originated from some single magma whose composition may be different in different regions; and, further, that it is the chemical differentiation of this primary magma which has given rise to the various kinds of igneous rocks.'

The fact that the diverse igneous rocks of certain districts are often bound together by common mineralogical and chemical characters which distinguish them from the corresponding rocks of certain other districts was clearly recognized by Prof. Judd in his well-known paper on the Volcano of Chemnitz, and subsequently crystallized by him in the happy expression petrographical province, as applied to any district in which the igneous rocks have certain common characteristics. The idea has been still further extended and elaborated by Prof. Iddings, who sees in the common characteristics the indications of a kind of blood-relationship or consanguinity, which can only be explained on the assumption that the different species of one and the same province have originated by differentiation from a single homogeneous magma.

Prof. Brögger, in his remarkable series of studies on the rocks of the Christiania district, has still further generalized this idea, and much of his work is directed towards the evolution of a genealogical tree, in which the twigs shall correspond to the final products of differentiation, the larger branches to some of the plutonic masses, and the trunk to the primordial homogeneous magma. The idea is a fascinating one: *se non è vero, è ben trovato.* But it must be admitted that we know very little about the causes of the assumed differentiation. These are supposed to be of two types: (1) those which affect the liquid magmas, and (2) those connected with the separation of the minerals. Magmatic differentiation is generally regarded as the most important, but it is the type of which we know least. Soret's principle, to which I have appealed, will, I fear, help us very little, though it is undoubtedly a *vera causa.* Mr. Harker has clearly shown that, as applied to a mass like the Carrock-Fell gabbro, it breaks down hopelessly when subjected to a quantitative

test. The principle of Gouy & Chaperon is even more unsatisfactory. Durocher's liquation-theory is, perhaps, more promising, but until it has been proved by actual experiment that there is a real analogy between baths of fused metals and silicate-magmas it cannot be said to rest upon an assured basis. Faraday's researches on lead-glass certainly suggest that gravity may act differentially on the constituents of silicate-magmas, independently of the principle of Gouy & Chaperon. Thus he found that glass taken from the top of pots not more than 6 inches deep might have a density of 3·28, while that from the bottom might have a density of 3·85; but there is some doubt as to whether the constituents were ever uniformly mixed in the molten state, and if not, whether sufficient time was allowed for diffusion to establish homogeneity. It is certain, however, that they were uniformly mixed in the solid state, and the experiments are therefore of great interest; for, if they do not prove differentiation in a molten mass, they prove that an uniform solid mass may become differentiated as it liquefies, by a kind of liquation-process analogous to that which takes place in the extraction of silver from copper.

Prof. Iddings has carefully considered the chemical compositions of groups of rocks, belonging to several different petrographical provinces, from the point of view of the differentiation-hypothesis, and has arrived at the conclusion that 'the simple-oxide molecules shift about independently of one another to a great extent.' If this conclusion be correct, it is clear that the phenomena cannot be explained by the hypothesis of a differentiation solely connected with the formation of known minerals; but this view does not appear to be accepted by Prof. Brögger, who believes

'that the process of differentiation must be referred to magmatic diffusion of definite chemical compounds to and from the cooling surface; further, that these diffusion-phenomena in all probability stand in direct relation to the order of crystallization of minerals in the corresponding magma; and lastly, that the order of crystallization, the nature of the differentiation, and the sequence of eruptions are all closely related phenomena.'

Differentiation dependent upon crystallization rests on a somewhat firmer basis, and it was this kind of differentiation that first attracted my attention. Mr. Clough, while mapping the Cheviot district, proved that the widespread series of andesitic lavas is cut by a number of quartz-felsite dykes. Why did quartz-felsite succeed andesite in the Cheviot district? This was the question which kept continually recurring to me during my examination of the rocks of

the district. Now, a microscopic examination of the andesites proved that the phenocrysts taken together must have the composition of a basic rock, for they were composed of labradorite, augite, and hypersthene, and therefore the glassy base present in some of the andesites must be allied to quartz-felsite in composition. The sequence established by Mr. Clough could therefore be explained by the assumption that the quartz-felsite magma represented the mother-liquor of the andesitic magma, after the phenocrysts had separated out. Thus, if crystallization had progressed in the plutonic mass to the stage represented by the phenocrysts of the lava, or a little further, and the mother-liquor had then been squeezed out as one squeezes water out of a sponge, or separated in any other way, and forced upwards into cracks in the overlying series of andesitic lava-flows, the question above referred to could be satisfactorily answered. I was fortunately able to test the theory quantitatively, for Mr. Waller had already analysed one of the quartz-felsites and Dr. Petersen had published analyses of the glassy base of one of the andesites and of the devitrified base of another. On comparing the mean of the two analyses of the base with the analysis of the quartz-felsite, it was found that of the eight constituents, six differed by less than ·4 per cent., silica differed by 2·2, and soda by 1·46.[1]

Differentiation dependent on crystallization is a fact which cannot be denied; for the igneous magma, except when it cools as a

[1] As the figures were not placed side by side in the original paper (Geol. Mag. 1885, p. 106), I so place them now:—

	I.	II.	III.	IV.	Diff.
SiO_2	66·25	65·16	65·70	67·9	+2·20
Al_2O_3	13·59	17·49	15·54	15·7	+0·16
Fe_2O_3	3·11	3·01	3·06	3·0	−0·06
CaO	2·75	0·84	1·79	1·4	−0·39
MgO	0·28	2·34	1·31	1·5	+0·19
K_2O	4·95	5·54	5·24	5·6	+0·36
Na_2O	2·25	3·68	2·96	1·5	−1·46
Loss	5·89	1·76	3·82	3·7	−0·12
	99·07	99·82	99·42	100·3	

I = Glassy base of hypersthene-andesite from Fairhaugh, Usway Burn, Cheviots. (Ebert.)

II = Devitrified base of andesite, 2 miles up Allerhope Burn. (Wulf.)

III = Mean of the two analyses.

IV = Quartz-felsite from dyke on the Coquet, ½ mile above Shillmoor Farm, Cheviots. (Waller.)

glass, separates into distinct minerals which do not, as a rule, consolidate simultaneously. But the acceptance of this fact does not involve the acceptance of the differentiation-theory of the origin of petrographical species, for, as M. Michel Lévy points out, the crystallization of a magma under ordinary circumstances does not commence until it has reached a pasty state. MM. Fouqué & Lévy observed no tendency to differentiation, of the kind required to produce petrographical species, in their celebrated synthetical experiments. The centres of crystallization were uniformly distributed throughout the masses, which were too viscous to allow of any appreciable movement of the first-formed minerals. Nevertheless, the facts observed by Darwin and others clearly prove that in large masses of lava, even at the surface of the earth, movement of crystals is possible in igneous magmas, and M. Michel Lévy himself admits that such movement may become an important factor under certain circumstances.

Mr. Harker has suggested another way in which crystallization may operate, so as to produce variation in a mass of rock. He has shown that the Carrock-Fell gabbro varies in composition from the centre to the sides, and that, as so frequently happens in eruptive masses, the latter are more basic than the former. He considers

'that the differentiation took place by diffusion in a fluid magma, but not as a process distinct from and quite anterior to crystallization. It was, as I believe, effected in a quasi-saturated magma, concurrently with the crystallization of the earlier-formed minerals; .... the characteristic of all [such occurrences] is that the several constituents are concentrated in a definite order, which is identical with the order in which they crystallize out from the magma.'

All theories which depend on diffusion or molecular flow have been criticized by Mr. Becker on the ground that the rate of diffusion is too slow to produce the results attributed to it in any reasonable time. He shows that, in the case of a column of water resting upon a layer of copper-sulphate, the lapse of 1,000,000 years would be required to produce sensible discoloration at a height of 350 metres, or semisaturation at a height of 84 metres; and he considers that the molecular flow of any compound in a silicate-magma would probably be at least 50 times less rapid, so that a mass of lava 1 cubic kilometre in volume

'would not have had time to segregate into distinctly different rocks by molecular flow if it had been kept melted since the close of the Archæan period.'

I am by no means averse to making heavy drafts on the bank of time for geological purposes, but unless some effective answer to Mr. Becker's arguments can be found, I think that we shall have to give up unaided molecular flow as an important factor in the origin of petrographical species.

Mr. Becker has not, however, simply confined himself to destructive criticism. He has proposed a theory of differentiation dependent on 'fractional crystallization.' During the cooling of a mass of molten matter in a dyke or laccolite, convection-currents will be established; these will act as stirrers, and, aided by diffusion, will tend rapidly to restore homogeneity in the liquid mass after it has been destroyed by the deposition of the first-formed crystals on the walls of the cooling surfaces. He compares a laccolite in which the marginal parts are different from the çentre, to a barrel of cider which has been frozen from the outside. During the earlier stages nearly pure ice is formed on the walls, while the alcohol is concentrated in the central portion; from this a liquor, gradually increasing in strength, may be drawn off as consolidation progresses. Here we see a further development of the idea originated by Darwin.

All forms of the differentiation-theory take as their starting-point a homogeneous magma, and then proceed to derive from it the different varieties of igneous rocks as we now see them by magmatic or some other form of differentiation. Are we justified in taking this view? As applied to certain districts, and especially to the Christiania district which Prof. Brögger has done so much to elucidate, it has proved of great value. But if we look at the general question, there are many facts which should give us pause. The earth's crust is certainly heterogeneous, and if magmas are, in any case, formed by the refusion of solid rocks, it is probable, as Mr. Becker has pointed out, that such magmas would be heterogeneous at the start. Even the refusion of homogeneous rocks may give rise to a heterogeneous magma, comparable to that produced by Faraday in his experiments on glass. The cause of some of the variations in igneous rocks is therefore probably to be sought for in actions which antedate the formation of the magmas. But even homogeneous magmas may become modified by the absorption or assimilation of the rocks through which they pass. This point has been clearly established and especially emphasized by M. Michel Lévy, Prof. Barrois, and Prof. Lacroix in France, and by Dr. Johnston Lavis, Prof. Sollas, Prof. Cole, and Mr. Harker in this country.

That it is a *vera causa* is admitted on all hands, but differences of opinion exist as to the extent to which it should be applied in explaining the origin of petrographical species.

If we study igneous rocks which have appeared at the surface as lavas, or have been intruded at moderate depths as dykes, sills, laccolites, or bosses, the evidence of absorption is, in my judgment, so slight as to be practically negligible; but if we pass from such regions to others in which plutonic rocks are found in relation with crystalline schists and study 'les appareils granitiques à racines profondes' of M. Michel Lévy, the case is different. It may be that the final solution of the problem of the origin of igneous magmas will be found in these regions; but here we touch a question which belongs to the future rather than to the past, and lies, therefore, beyond the scope of this Address. So far as I am concerned, I will confess that my ideas are not fixed. At present I am not disposed to attach much importance to theories involving differentiation *in situ* by unaided molecular flow in dykes and laccolites; but rather to attribute such variation as does occur to successive eruptions, or to a continuous change in the nature of the material during the process of intrusion. The great difficulty in applying any theory that involves differentiation *in situ* to such cases arises from the slight effect of the igneous magmas on the containing walls—a fact which negatives the idea that the material arrived at the place where we now find it in a condition of superfusion, or that it remained fluid long enough to enable any considerable diffusion to take place.

Our ideas as to the origin of igneous rocks are still 'en pleine évolution.' Conditions are rapidly changing in consequence of discoveries in geology and physical chemistry. Rival theories are struggling for existence, and although it is safe to predict that some will become extinct, that others will be modified, and that natural selection will finally bring about the survival of the fittest, it is impossible to determine, at present, the relative importance of those which claim our attention.

The origin of petrographical species, so far as the igneous rocks are concerned, is a problem the final solution of which has been handed on by the nineteenth century to its successor.

February 20th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

George William Sawyer Brewer, Esq., Ryeworth Villa, Charlton Kings, Cheltenham; James Carter, Esq., 1 Granville Road, Blackburn; Louis Charles Deverell, Esq., F.C.S., 104 Upper Thames Street, E.C.; Percy Hawkins, Esq., Beswada, Kistna District (Madras Presidency); and L. Clements Henry, Esq., F.R.G.S., Axim, Gold Coast (West Africa), were elected Fellows of the Society.

The List of Donations to the Library was read.

The Address which it was proposed to submit to His Majesty the King, on behalf of the President, Council, and Fellows, was read as follows, and the terms thereof were approved:—

'TO THE KING'S MOST EXCELLENT MAJESTY.

'May it please Your Majesty,

'We, Your Majesty's most dutiful and loyal subjects, the President, Council, and Fellows of the Geological Society of London, humbly beg leave to offer to Your Majesty our most profound and heartfelt sympathy in the great sorrow which has fallen on You in the death of our late beloved Sovereign Queen Victoria, and to most respectfully express the deep grief that we, in common with all Your Majesty's subjects, feel at the great loss which has befallen the Nation.

'While thus expressing our grief, we most humbly beg leave to offer to Your Majesty our most sincere and unfeigned congratulations on Your Majesty's Accession to the Throne of Your Ancestors. Our knowledge of the great interest which Your Majesty has always taken in all matters relating to the welfare of Your subjects makes us feel with confidence that Science will continue to advance during Your Reign as in that of Her late Majesty of beloved memory. We recall with pride that Your Majesty's Father, the late Prince Consort, was for many years a Fellow of this Society.

'And we shall ever pray that Your Majesty may long be spared to reign over a happy and contented people.'

Prof. J. B. Harrison, alluding to a series of views of parts of the interior of British Guiana, which he laid on the table, remarked that the photographs had been taken by his colleague, Mr. H. I. Perkins, F.G.S., Acting Commissioner of Mines in British Guiana, during their recent geological investigations into the structure of the goldfields of that colony. The views well illustrate the general characteristics of the densely wooded country in which the gold-bearing areas occur, and give some idea of the difficulties which affect the work of the mining prospector and of the field-geologist in that colony.

Several of the photographs illustrate rapids, cataracts, and falls which so frequently occur along the courses of some of the vast rivers of that part of South America, and show the differing forms of weathering of various igneous rocks and of horizontally-bedded sandstones and conglomerates in the tropics.

Among the photographs are several fine views of the Kaieteur

Falls on the Potaro River, a tributary of the Essequibo. These falls, which were discovered by a Fellow of the Geological Society, Mr. C. Barrington Brown, in the course of his geological reconnaissance of the colony about thirty years ago, occur near the escarpment of the great sandstone-formation which is so largely developed in the Guianas and in Brazil. The falls are over a ledge of very coarse siliceous conglomerate, some 18 or 20 feet thick, which overlies a thickness of about 1000 feet of almost horizontally-bedded sandstones. The river above the falls is about 400 feet broad and from 18 to 20 feet deep, and plunges vertically, as a great curtain of water, for 740 feet, into a vast chasm at the extremity of a deep valley which it has eroded for a distance of about 17 miles from the escarpment of the sandstones. During the first 3 or 4 miles of its course from the falls through the valley, the river descends for about 400 feet by a series of cataracts and rapids. The valley, which is eroded in places through the sandstones into the underlying igneous rocks, is of surpassing beauty, and offers many features of marked geological interest. One of the views, taken when the water was low after a long-continued drought, shows very clearly the great cave which the spray of the falling water has cut out from the softer sandstone-strata.

Others of the views show the somewhat primitive methods employed in prospecting and in working the placer-claims for gold.

With reference to a few rock-specimens exhibited, Prof. Harrison stated that they were of diamond-drill cores from the Omai-Creek claims on the Essequibo River, and that they fairly represented the principal auriferous rocks of that district. Omai Creek is a small stream flowing into the Essequibo at about 130 miles above its mouth, and the country through which it flows is usually diabase (dolerite) and its decomposition-products. From a part of the bed of one of the tributaries of this stream (Gilt Creek), about 500 feet in length by 50 in breadth, some 60,000 ounces of gold and some hundreds of small diamonds have been recovered by the somewhat crude methods of working hitherto in use. The specimens shown were of quartz-diabase and of a massive epidiorite, the oldest auriferous rocks in the district; of an intrusive aplite or possibly altered albite-granite, the contents of which in gold (apparently of secondary origin) vary from 1 to 15 dwts. per ton, but in places where it is intersected by veins of secondary quartz may rise to 40 or 50 ounces per ton of the rock; of diabase or dolerite, so far as is at present known the rock of most recent origin in the colony, and it is, in the speaker's experience, invariably auriferous, appearing in fact to be the principal source of gold in the Guianas; and of highly-altered porphyroids, in parts changed almost completely to epidote-chlorite rocks, in others to sericite-rocks wherein the original porphyrites and quartz-porphyrites can be discerned only with difficulty, and these in that district form the practically non-auriferous country-rock.

The so-called placer-deposits of British Guiana form a

striking exception to the generally received text-book view of the origin of placer gold-deposits. In the speaker's experience the Guiana deposits have not been derived to any great extent from pre-existent quartz-reefs containing gold, but from the degradation *in situ* of diorites, epidiorites, and hornblende-schists originally more or less auriferous, or in places of mineralized masses and dykes of acidic or of intermediate rocks; but principally of bosses, sills, and dykes of an intrusive diabase or dolerite of at present unknown geological age, which appear to be always gold-bearing to a minute extent, while in places the selvages of the dykes may contain as much as 5 ounces of gold per ton of the rock. He hoped at some future opportunity to return to the subject, and to lay before the Society the evidence which he had obtained for the above statements, and also the results of many observations bearing on the genesis of placer gold-deposits, and on the concentration of the minute amounts of the precious metal contained in igneous rocks in their degradation-products by processes of chemical solution and redeposition under tropical conditions.

Finally, he reminded the meeting that the area in which he is at present working forms but a small portion—some 300 miles in breadth—of that great, though almost undeveloped, mineralized belt which extends from El Callao in Venezuelan Guiana to near the mouth of the Amazon in Brazilian Guiana.

Prof. Edward Hull made a communication, illustrated by lantern-slides, on the submerged valley opposite the mouth of the River Congo. The position of this submerged valley has been ascertained by Mr. Edward Stallybrass and Prof. Hull, by contouring the floor of the ocean with the aid of the soundings recorded on the Admiralty Charts. The sides of the valley are steep and precipitous and clearly defined, the width varying from 2 to 10 miles, and the length across the Continental platform being about 122 miles. It is continuous with the Valley of the Congo, and its slope is uninterruptedly downward in the direction of the abyssal floor. The steepness of the sides indicates that they are formed of very solid rocks.

Several other submerged valleys off the coast of Western Europe were described for comparison. In most cases the landward end of the submerged river-channel is filled with silt, etc. for some distance from the mouth of the actual river; but, farther out, its course becomes quite distinct towards its embouchure at the edge of the Continental platform. Among the valleys specified were those off the mouth of the Tagus and the Lima, the Adour, and the Loire, and those in the English and Irish Channels.

The following communication was read:—

'On the Beds between the Millstone Grit and Mountain Limestone of Pendle Hill, and their Equivalents in certain other Parts of Britain.' By Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S., and J. Allen Howe, Esq., B.Sc., F.G.S.

In addition to the photographs and specimens described on p. lxxxviii the following were exhibited:—

Specimens of Rocks and Fossils from the Millstone Grit Series, with Rock-sections and Lantern-slides, exhibited by Wheelton Hind, M.D., B.S., F.R.C.S., F.G.S., and J. Allen Howe, Esq., B.Sc., F.G.S., in illustration of their paper.

Vertical Sections, Geological Survey of England & Wales, Nos. 83 & 84: South Wales Coalfield, by A. Strahan & W. Gibson, presented by the Director-General of H.M. Geological Survey.

March 6th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Joseph Alfred Bean, Esq., Moot Hall, Newcastle-upon-Tyne, was elected a Fellow of the Society.

The List of Donations to the Library was read.

The President read the following resolution, which had been passed unanimously by the Council at their Meeting that afternoon:—

'That this Council desire to place on record their deep sense of the loss occasioned to Geological Science by the death of Dr. George M. Dawson, C.M.G., and to express their sincere sympathy with his family in their bereavement.'

The President announced that Sir Archibald Geikie, D.Sc., D.C.L., LL.D., F.R.S. (President from 1890 to 1892), had presented to the Society a large framed photographic portrait of himself.

The following communications were read:—

1. 'Recent Geological Changes in Northern and Central Asia.' By Prof. George Frederick Wright, F.G.S.A. (Communicated by the President.)

2. 'The Hollow Spherulites of the Yellowstone and Great Britain.' By John Parkinson, Esq., F.G.S.

The following specimens were exhibited:—

Rock-specimens and Microscope-sections exhibited by John Parkinson, Esq., F.G.S., in illustration of his paper.

Limestone bored by a Species of Worm (?), from Hempstead Beach (Isle of Wight), exhibited by W. P. D. Stebbing, Esq., F.G.S.

March 20th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

George Edward Blundell, Esq., Wellington College (Berkshire), and Thomas Andrew Oliver, Esq., Southfield House, Bramcote (Nottinghamshire), were elected Fellows of the Society.

The List of Donations to the Library was read.

Mr. H. B. Woodward called attention to a polished slab of Landscape Marble, or Cotham Stone, from the Rhætic Beds near Bristol, which had kindly been lent for exhibition by Mr. Frederick James, Curator of the Maidstone Museum. The specimen showed that, after the arborescent markings had been produced in the soft mud, some irregular and partial solidification took place in the upper layers of the deposit; and then, during contraction, a kind of subsidence occurred, of the upper and harder portions into the lower and softer materials. This subsidence was accompanied by a breaking-up of the harder portions, suggesting a comparison (in miniature) with 'broken beds' and even crush-conglomerates. The specimen was of considerable interest, as illustrating the mechanical changes produced during solidification.

The following communications were read:—

1. 'On a Remarkable Volcanic Vent of Tertiary Age in the Island of Arran, enclosing Mesozoic Fossiliferous Rocks.'

[Communicated by permission of the Director-General of H.M. Geological Survey.]

Part I.—'The Geological Structure.' By Benjamin Neeve Peach, Esq., F.R.S.L. & E., F.G.S., and William Gunn, Esq., F.G.S.
Part II.—'Palæontological Notes.' By Edwin Tulley Newton, Esq., F.R.S., F.G.S.

2. 'On the Character of the Upper Coal-Measures of North Staffordshire, Denbighshire, South Staffordshire, and Nottinghamshire; and their Relation to the Productive Series.' By Walcot Gibson, Esq., F.G.S.

[Communicated by permission of the Director of H.M. Geological Survey.]

The following specimens, etc. were exhibited, in addition to that described above:—

Rocks and Fossils from Arran, exhibited by permission of the Director of H.M. Geological Survey, in illustration of the paper by

Messrs. B. N. Peach, F.R.S.L. & E., F.G.S., W. Gunn, F.G.S., and E. T. Newton, F.R.S., F.G.S.

Rocks and Fossils of the Upper Coal-Measures of North Staffordshire, etc., exhibited by Walcot Gibson, Esq., F.G.S., in illustration of his paper.

A copy of the 1st Edition (1873) of the Geological Sketch-Map of Cape Colony, drawn up and presented by E. J. Dunn, Esq., F.G.S.

March 27th, 1901.

Special General Meeting: 8 P.M.

J. J. H. TEALL, Esq., M.A., V.P.R.S., President, in the Chair.

This meeting was convened on the requisition of the following five or more Fellows, namely:—The Rev. J. F. BLAKE, Dr. HENRY WOODWARD, Dr. A. SMITH WOODWARD, Sir HENRY H. HOWORTH, Dr. F. A. BATHER, Mr. R. BULLEN NEWTON, Mr. H. A. ALLEN, Mr. C. DAVIES SHERBORN, Dr. F. L. KITCHIN, Mr. UPFIELD GREEN, and Mr. G. E. DIBLEY; for the purpose of considering the following matters:—

1. The present state of the Society's Museum.

2. The steps necessary to be taken for putting the collections therein contained into a satisfactory condition, if retained in the Museum; or otherwise the desirability and conditions of their disposal elsewhere, as may be decided on.

3. The arrangements necessary to be made, in order to keep the collections constantly in a satisfactory condition, if their retention is decided on.

4. The amount necessary to be expended (*a*) in the first instance, and (*b*) annually, to carry out the decisions of the Meeting. Also to authorize the Council to incur this expenditure; and finally to make such order concerning the estates or revenues of the Society as to the Fellows assembled in such General Meeting shall appear useful for the purpose of carrying out their decisions.

The Rev. J. F. BLAKE proposed, and Mr. R. BULLEN NEWTON seconded, the following resolutions:—

1. That the general collection in the Society's Museum be limited to such specimens as have been or may hereafter be definitely referred to, by name, description, or figure, in the Society's publications, or in such other works as may be agreed upon by the Council.

2. That the specimens retained be thoroughly cleaned, provided with fresh labels additional to the old ones, placed in drawers or boxes designed to exclude dust, and arranged with reference to the papers or works wherein they are referred to, and that a catalogue of such retained specimens be printed.

3. That the remaining specimens be disposed of in such a way as the Council may direct.

4. That the Council be authorized to expend, either out of capital or income, so much as may be necessary to carry these resolutions into effect.

The following Amendment was moved by Sir HENRY HOWORTH, F.R.S., and seconded by Prof. W. BOYD DAWKINS, F.R.S. :—

That in the opinion of this Meeting the time has now come when this Society shall transfer its collections to some other Museum.

The Amendment was put, and there voted for it 22, against 19.

The Amendment was therefore carried, and on being again put as a substantive resolution there voted for it 26, against 19.

The Amendment was therefore declared carried as the Resolution of the Meeting.

April 3rd, 1901.

HORACE W. MONCKTON, Esq., F.L.S., Vice-President, in the Chair.

Joseph S. Bridges, Esq., B.Sc., 45 Thistlethwaite Road, Clapton, N.E.; and Thomas Birch Freeman Sam, Esq., C.E., c/o Messrs. F. & A. Swanzy, 147 Cannon Street, E.C., and Cape Coast Castle (Gold Coast), West Africa, were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Igneous Rocks and Associated Sedimentary Beds of the Tortworth Inlier.' By Prof. Conwy Lloyd Morgan, F.R.S., F.G.S., and Sidney Hugh Reynolds, Esq., M.A., F.G.S.

The following specimens and maps were exhibited:—

Specimens, Rock-sections, and Lantern-slides, exhibited by Prof. C. Lloyd Morgan, F.R.S., F.G.S., and S. H. Reynolds, Esq., M.A., F.G.S., in illustration of their paper.

Curiously-worn Bunter Pebble from the Drift at Woolmer Green (Hertfordshire), exhibited by A. E. Salter, Esq., B.Sc., F.G.S.

Relief-Map of Canada and the United States (1 inch = 250 miles), 1900, presented by the Director of the Geological Survey of Canada.

Carte Géologique du Massif du Mont-Blanc, $\frac{1}{50,000}$, drawn up and presented by L. Duparc and L. Mrazec.

April 24th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Vaughan Cornish, Esq., M.Sc., F.C.S., F.R.G.S., 72 Princes Square, London, W.; Ronald Audley Martineau Dixon, Esq., 46 Marlborough Avenue, Hull; and Charles Kenelm Digby Jones, Esq., 12 Chester Street, Edinburgh, were elected Fellows; and Prof. Friedrich Johann Becke, of Vienna, was elected a Foreign Correspondent of the Society.

The List of Donations to the Library was read.

The Secretary read the following letter, which had been received from H.M. Secretary of State for the Home Department:—

Home Office, Whitehall, 3rd April, 1901.

'Sir,

I am commanded by the King to convey to you hereby His Majesty's thanks for the Loyal and Dutiful Address of the President, Council, and Fellows of the Geological Society of London expressing sympathy on the occasion of the lamented death of Her late Majesty Queen Victoria, and congratulation on His Majesty's Accession to the Throne.

'I am, Sir,
'Your obedient Servant,
'Chas. T. Ritchie.'

J. J. H. Teall, Esq.,
Geological Society of London,
Burlington House, W.

The President drew attention to a framed and glazed copy of the Table of the British Strata by Dr. Henry Woodward, F.R.S., F.G.S., and Horace B. Woodward, Esq., F.R.S., F.G.S., which the former had kindly presented to the Society.

In exhibiting a specimen of *Crioceras occultus* from the Snettisham Clay of Heacham, near Hunstanton, Prof. H. G. Seeley said that he had no doubt that the *Trigonia hunstantonensis* and *Crioceras occultus*, originally described as from the Hunstanton Limestone, were from the clay at Heacham. The example of *Crioceras* now shown was found by Mr. F. Deighton, of Cambridge. It only differs as a variety from the type figured in 1865.

The following communications were read:—

1. 'Notes on Two Well-Sections.' By the Rev. R. Ashington Bullen, B.A., F.L.S., F.G.S.

2. 'On the Geological and Physical Development of Antigua';

3. 'On the Geological and Physical Development of Guadeloupe';

4. 'On the Geological and Physical Development of Anguilla, St. Martin, St. Bartholomew, and Sombrero'; and

5. 'On the Geological and Physical Development of the St. Christopher Chain and Saba Banks': the four last-named papers being by Prof. J. W. Spencer, Ph.D., M.A., F.G.S.

In addition to the exhibits mentioned on p. xciv, the following specimens, photographs, and maps were exhibited:—

Specimens exhibited by the Rev. R. Ashington Bullen, B.A., F.L.S., F.G.S., in illustration of his paper.

Specimens of Rocks and Fossils from Antigua, from the Geological Society's Museum, collected by Dr. N. Nugent, Major-Gen. Sir Patrick Ross, G.C.M.G., and Mr. Guilding, exhibited in illustration of Prof. J. W. Spencer's paper on that island.

Photographs of probable Moraine on which Scratched Boulders are found, near Lea Schools, Matlock Bath (Derbyshire), exhibited by W. J. P. Burton, Esq., F.G.S.

Photographs showing the Conformity of the Witteberg Series to the Bokkeveld Series, and of the latter to the Table-Mountain Sandstone, by E. H. L. Schwarz, Esq., A.R.C.S., of the Geological Survey of Cape Colony, exhibited by Prof. J. W. Judd, C.B., LL.D., F.R.S., F.G.S.

Five Sheets of the Geological Map of Rumania, presented by the Director of the Museum of Geology, Bukharest.

May 8th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Frecheville Joseph Ballantine-Dykes, Esq., Kwala Lumpor, Selangor (Straits Settlements); and George William Roome, Esq., B.Sc., Normal College, Bangor (North Wales), were elected Fellows of the Society.

The List of Donations to the Library was read.

The following communication was read:—

'The Influence of the Winds upon Climate during the Pleistocene Epoch; a Palæo-Meteorological Explanation of some Geological Problems.' By F. W. Harmer, Esq., F.G.S.

The following specimens, photographs, and maps were exhibited:—

Specimens from the Cretaceous of Texas, exhibited by E. A. Martin, Esq., F.G.S.

Six Photographs of the Contorted Glacial Drifts of the Norfolk Coast, between Cromer and Sheringham, taken and exhibited by A. T. Metcalfe, Esq., F.G.S.

Four Sheets of the Geological Map of the Grand Duchy of Hesse, scale $\frac{1}{25,000}$, by G. Klemm and C. Chelius, 1901, presented by the Director of the Grand Ducal Survey.

May 22nd, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

The List of Donations to the Library was read.

Mr. George Abbott, in exhibiting some specimens of Cellular Limestone from the Permian beds at Fulwell, Sunderland, which he proposed to present to the British Museum (Natural History), remarked that their interest depended upon the assumption that they were entirely inorganic. Although showing a remarkable resemblance to corals, yet no zoologist or geologist had yet claimed them as organic. If this surmise were correct, the carbonate-of-lime-molecules—probably when amorphous—must have had some inherent molecular directive force which produced the numerous distinct patterns in their structure. These fall into four distinct classes:—honeycomb (two kinds), coralloid, and pseudo-organic, the last-named being remarkable for having a constant discoidal shape, and therefore those of this class must have had their external form also controlled by the hypothetical force. Each class appears to have passed through four stages of 'growth' and to have undergone some marvellous rearrangements of the particles while in the solid condition. So far as he knew, no one had previously attempted to classify the different patterns, nor had anyone, except William King, in his work on 'Permian Fossils,' offered any theory as to the formation of this cellular structure in the Magnesian Limestone.

The following communications were read:—

1. 'On the Skull of a Chiru-like Antelope from the Ossiferous Deposits of Hundes (Tibet).' By Richard Lydekker, Esq., B.A., F.R.S., F.G.S.

2. 'On the Occurrence of Silurian [?] Rocks in Forfarshire and Kincardineshire along the Eastern Border of the Highlands.' By George Barrow, Esq., F.G.S.[1]

3. 'On the Crush-Conglomerates of Argyllshire.' By J. B. Hill, Esq., R.N.[1] (Communicated by R. S. Herries, Esq., M.A., Sec.G.S.)

In addition to the specimens described above, the following specimens and map were exhibited:—

Skull of a Chiru-like Antelope from the Ossiferous Deposits of Hundes (Tibet), from the Geological Society's Museum, and a Skull of a recent Antelope, exhibited by R. Lydekker, Esq., B.A., F.R.S., F.G.S., in illustration of his paper.

Rock-specimens and Microscope-sections, exhibited by G. Barrow, Esq., F.G.S., in illustration of his paper.

[1] Communicated by permission of the Director of H.M. Geological Survey.

Six specimens of the so-called 'Clay-Concretions' from Vermont (U.S.A.), possessing unusual symmetry. They are really calcareous concretions (containing about 50 per cent. of calcium-carbonate) from the river-drift clays of the Connecticut Valley. Exhibited by George Abbott, Esq., M.R.C.S.

Geological Survey of Norway Map, $\frac{1}{100,000}$, No. 25 D. Lillehammer, by T. Muenster, 1899, presented by the Director of that Survey.

June 5th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

Henry Johnson, Esq., Castledale, Dudley (Worcestershire), was elected a Fellow of the Society.

The Names of certain Fellows of the Society were read out for the first time, in conformity with the Bye-Laws, Sect. VI. Art. 5, in consequence of the non-payment of the Arrears of their Contributions.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Passage of a Seam of Coal into a Seam of Dolomite.' By Aubrey Strahan, Esq., M.A., F.G.S.[1]

2. 'On some Landslips in Boulder-Clay near Scarborough.' By Horace Woollaston Monckton, Esq., F.L.S., V.P.G.S.

The following specimens, photographs, and lantern-slides were exhibited:—

Specimens and Microscope-sections of Dolomite from the Wirral Colliery (Cheshire), exhibited by A. Strahan, Esq., M.A., F.G.S., in illustration of his paper.

Photographs and Lantern-slides, exhibited by H. W. Monckton, Esq., F.L.S., V.P.G.S., in illustration of his paper.

June 19th, 1901.

J. J. H. Teall, Esq., M.A., V.P.R.S., President, in the Chair.

George Abbott, Esq., M.R.C.S., 33 Upper Grosvenor Road, Tunbridge Wells; William John Ball, Esq., 33 Hungerford Road, Crewe; and Prof. Edward Thomas Mellor, B.Sc., Vaynor, Belmont Road, Portswood, Southampton, were elected Fellows of the Society.

[1] Communicated by permission of the Director of H.M. Geological Survey.

The Names of certain Fellows of the Society were read out for the second time, in conformity with the Bye-Laws, Sect. VI. Art. 5, in consequence of the non-payment of the Arrears of their Contributions.

The List of Donations to the Library was read.

The following communications were read:—

1. 'On the Use of a Geological Datum.' By Beeby Thompson, Esq., F.G.S., F.C.S.

2. 'On Intrusive, Tuff-like, Igneous Rocks and Breccias in Ireland.' By James R. Kilroe, Esq., and Alexander McHenry, Esq., M.R.I.A.[1] (Communicated by R. S. Herries, Esq., M.A., Sec.G.S.)

The following specimens were exhibited:—

Rock-specimens of Tuff-like Igneous Rocks from Ireland, exhibited by J. R. Kilroe, Esq., and A. McHenry, Esq., M.R.I.A., in illustration of their paper.

Drift-worn Palæolithic Implement found at Orpington (Kent), exhibited by George Clinch, Esq., F.G.S.

Rock-specimens from the Salcombe district (South Devon), showing crumpling and folding, exhibited by William P. D. Stebbing, Esq., F.G.S.

[1] Communicated by permission of the Director of H.M. Geological Survey.